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A Comprehensive Guide to Fuel Management Practices for Dry Mixed Conifer Forests in the Northwestern United States

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Dry Mixed Conifer Forest Ecology



Planning and Implementation



Fuel Treatment Feasibility and Longevity



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Abstract

This guide describes the benefits, opportunities, and trade-offs concerning fuel treatments in the dry mixed conifer forests of northern California and the Klamath Mountains, Pacific Northwest Interior, northern and central Rocky Mountains, and Utah. Multiple interacting disturbances and diverse physical settings have created a forest mosaic with historically low- to mixed-severity fire regimes. Analysis of forest inventory data found nearly 80 percent of these forests rate hazardous by at least one measure and 20 to 30 percent rate hazardous by multiple measures. Modeled mechanical treatments designed to mimic what is typically implemented, such as thinning, are effective on less than 20 percent of the forest in single entry, but can be self-funding more often than not. We provide: (1) exhaustive summaries and links to supporting guides and literature on the mechanics of fuel treatments, including mechanical manipulation, prescribed fire, targeted grazing and chemical use; (2) a decision tree to help managers select the best mechanical method for any situation in these regions; (3) discussion on how to apply prescribed fire to achieve diverse and specific objectives; (4) key principles for developing an effective monitoring plan; (5) economic analysis of mechanical fuel treatments in each region; and (6) discussion on fuel treatment longevity. In the electronic version of the document, we have provided links to electronic copies of cited literature available in TreeSearch online document library (http://www.treesearch.fs.fed.us/)

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This fuel synthesis for the dry mixed conifer forests would not have been possible without critical contributions from a great many managers, scientists, and other natural resource professionals. Although the listed authors did most of the writing and are collectively and solely responsible for accuracy and completeness, the content and structure of the synthesis was driven by the hundreds of comments, questions, and anecdotes shared with us by managers and scientists. We interviewed over 50 specialists throughout the synthesis area and are indebted to every one of them. Thank you for your time and effort! Many thanks to those who helped out by providing peer-review: Andris Eglitis, Barry Bollenbacher, Daron Reynolds, David Powell, David Peterson, Deirdre Dether, Gabe Dumm, Geoff Babb, Louisa Evers, Jason Moghaddas, Jonathan Oppenheimer, Morris Johnson, Roby Darbyshire, Tim Bumgarner, Tobin Kelly, Tyre Holfeltz, Morgan Varner, and Nikia Hernandez. Your reviews were extensive and informative and we addressed every comment, and many of them led to revisions, which we believe improved this product. We are particularly indebted to Louisa Evers. Her knowledge of management history was so impressive that we invited her to help write Chapter 4, “Actions and Impacts of Past Management,” and she graciously agreed. Jeff Halbrook’s comments on mechanical fuel reduction treatments were helpful in developing the flow chart of equipment selection for Chapter 8. Morgan Varner, thank you for providing a review of decision tools at the critical time when we needed it. Reading proofs prior to publication takes time and focused concentration to catch subtle errors in the manuscript; we needed an individual who was not directly involved in the writing to conduct a final review; in addition to the authors. Lance Asherin set aside the time to critically review the manuscript; we are grateful for the errors he identified and appreciate his professional expertise and comments.

James Donley, Nichole Studevant, and Tess Pinkney were instrumental in preparing the document; they compiled the reference list and information for several tables and figures. There were also key people who worked with Jeremy Fried to compile the information we present in Chapters 5 and 11. They include Demetrios Gatziolis, who assisted with R script programming for the appendices, Glenn Christensen, who resolved FVS keyfile issues during the BioSum analysis, and Larry Potts, who wrote, and then repeatedly debugged and revised BioSum to enable the analysis to be completed successfully.

Our science writer, Josh McDaniel, proved masterful at blending our diverse writing styles to help create a consistent and integrated document. His knowledge of wildland fire and his writing expertise made this synthesis far more accessible than would otherwise have been possible. The professional appearance and publication standards reflected in this document can only be attributed to Lane Eskew and the Publishing Services staff for the Rocky Mountain Research Station. Lindy Larson, Lane Eskew, Suzy Stephens, Loa Collins, and Nancy Chadwick provided their expertise in editing, developing figures, and layout of the document. Suzy was instrumental in creating the interactive reference list. We feel privileged to have the support of all these highly capable professionals.

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Contents

Chapter 1
Introduction

Preamble

Idaho's Warm Lake Basin sits at 5,300 ft near the origin of the South Fork of the Salmon River in the Payette Crest and Salmon River Mountain ranges. The area is a popular summer vacation destination, and summer homes, cabins, and campgrounds are scattered throughout the mixed conifer forests that cover the basin (Graham and others 2009).

Because of the increasing fire risk to the wildland-urban interface (WUI) around Warm Lake, the Forest Service began fuel treatments in the mid-1990s to reduce the amounts, distribution, and juxtaposition of surface and ladder fuels by homes and campgrounds. Seven prescribed burns totaling over 8,000 acres were used to clean the forest floor of litter and fine woody fuels (≤3 inches in diameter) and kill many of the small trees that served as ladder fuels in these dry mixed conifer forests. Mechanical fuel treatments were used on lodgepole pine near cabins and homes to reduce canopy density, remove ladder fuels, and raise canopy base heights. A total of over 9,000 acres were treated at a cost of about $181 per acre (Graham and others 2009).

In August of 2007, the fuel treatments were put to the test when two wildfires, the Monumental and North Fork Fires, burned 150,000 acres in the vicinity of Warm Lake. Only two structures were burned during the fires; without the treatments, many more would likely have burned. The fuel treatments did not stop the fires but they disrupted their advance and influenced burn severity. Although fire behavior changed from a crown to a surface fire when the flames entered the treatments, the fire moved into the treatments 200 to 400 feet before fire intensity was reduced sufficiently to leave unburned soils and live trees. The treatments produced suppression opportunities (creating safe zones and locations suitable for igniting burnouts and facilitating construction of hand- and machine-built fire line) that would not have otherwise been available. Post-fire surveys showed that the treatments helped to create a mosaic of burn patterns, forest structures, and species compositions that will result in enhanced wildlife habitat and more fire resilient forests in the future.

The way the North Fork and Monumental Fires interacted with fuel treatments, roads, and associated suppression efforts reinforced the notion that the treatment of surface fuels, ladder fuels, and crown fuels (in this order of importance), and the location and juxtaposition of those treatments, are major determinants of both wildfire intensity and burn severity. The Warm Lake experience exemplifies how fuel treatments combined with fire suppression can affect a wildfire outcome in dry mixed conifer forests (Graham and others 2009).

Setting

In the United States, dry mixed conifer forests occur from the northern and central Rocky Mountains to the Pacific Northwest and into the Great Basin, Utah, and California and throughout the Southwest (fig. 1). These forests are associated with complex fire regimes. Predominantly low and mixed severity wildfires historically burned through these forests leaving a variety of forest compositions and structures. Since the 1800s, insects, disease, fire exclusion, livestock grazing, timber harvesting,

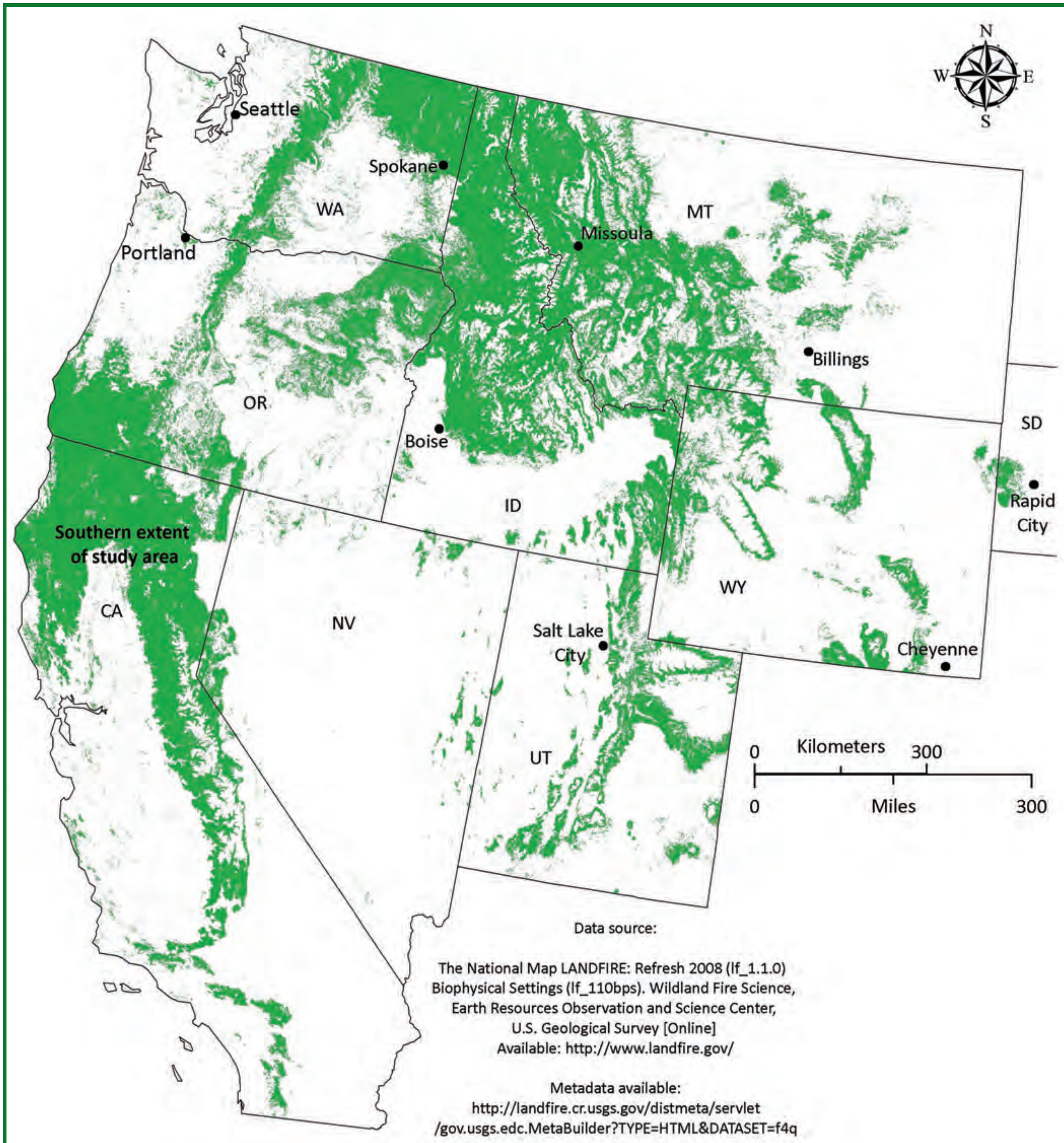

Figure 1.1. The focus of the synthesis is the dry mixed conifer forests in Idaho, Montana, Wyoming, South Dakota, Utah, Oregon, Washington, and northern California.

and widespread human settlement have shaped these forests. Stand structure, species composition, fuel dynamics, and forest succession have all been affected by fire regimes in these forests. One consequence is a proliferation of larger and more intense wildfires, such as the 2002 Biscuit Fire (500,000 acres), the 2007 Cascade Complex (302,376 acres), and the 2006 Tripod Complex (113,011 acres) (Prichard and others 2010; Thompson and Spies 2009).

Dry mixed conifer forests challenge ecological classification systems because of the diversity and complexity of the landscapes where they occur. Many contain ponderosa pine and a mixture of other tree species in the overstory and understory and are highly productive, in contrast with very dry sites in the southwestern United States that resemble a ponderosa pine monoculture. Dry mixed conifer forests often mix with both drier and wetter forests, creating a mosaic of forest types quite unlike the expansive stands of comparatively pure ponderosa pine found elsewhere in the West. Moreover, these forests occupy a variety of aspects, slopes, and topographic contexts, further contributing to the classification challenge. Past management and disturbance are also influential; ponderosa pine may not be present on every site classified as dry mixed conifer due to selective harvesting, fire exclusion, succession, fire, insects, disease, or other disturbances. The different combinations of disturbances and successional pathways can lead to a vast number of possible ground level and overstory vegetative compositions, structures, and mosaics (Jain and Graham 2005; Perry and others 2011; Quigley and others 1997a).

Moreover, the disturbances that influence the species and structural diversity of these forests also operate at different time frames and spatial extents. Therefore, regardless of the fuel treatment location, its timing, or its objective, it is important to recognize the dynamic nature of the forests. In other words, “one size does not fit all.” Fuel treatments should be tailored to the forest setting and the values they are designed to protect.

The design and implementation of fuel treatments, however, is not solely influenced by forest and fire ecology. Social issues necessarily play an important role. For example, approximately 9 percent of the land area in the contiguous United States is considered wildland–urban interface (WUI) where houses intermingle with wildland vegetation. However, approximately 39 percent of all houses occur within the WUI (Radeloff and others 2005). Dry mixed conifer forests of the American West in particular contain many areas that are attractive to those who prefer rural settings for living and recreation. Accordingly, fuel treatments in and around WUI communities focus on creating forest structures and compositions designed to protect homes and infrastructure and to enhance fire suppression effectiveness and firefighter safety. In contrast, much of the land base in Idaho, for example, is federally administered; consequently, treatments in the less populated areas may favor increasing forest resilience and may or may not be directly related to facilitating suppression.

Purpose

The purpose of this guide is to provide the most up-to-date information regarding the benefits, challenges, opportunities, and trade-offs among the different strategies and tools related to fuel treatment applications within dry mixed conifer forests of the western United States. Our geographic area includes the dry mixed conifer forests in northern California and Klamath, Pacific Northwest Interior, northern and central Rocky Mountains, and Great Basin (primarily in Utah) and covers over 37 million acres. This guide for managing fuels is not a “how to” or “cookbook” for fuels management, but rather an information resource that can be used to help plan and execute forest treatments directed at altering fire behavior and burn severity.

All live and dead vegetation is fuel in dry mixed conifer forests. Thus, regardless of objective, all vegetation manipulation alters fuels and fuel dynamics. This document cannot prescribe or predict all of the possible outcomes of treating fuels in dry mixed conifer forests, but it does describe many common region-wide patterns as well as some of the more unique, site-specific observations associated with fuel treatments in these forests.

Throughout this guide, we emphasize the importance of designing fuel treatments with the full range of potential fire behaviors in mind, in addition to the possible fuel and weather conditions. However, it is also important to address other disturbances and factors (for example, climate, diseases, insects, snow, and wind) that may impact treatment effectiveness and longevity. Because vegetation regenerates and develops rapidly in dry mixed conifer forests, ladder fuel development is also rapid, so maintenance (re-treatment) may be essential for long-term effectiveness. Monitoring fuel development over short and long time scales and adjusting treatment schedules based on what is learned can ensure effectiveness in mitigating the effects of an unwanted fire.

There are many ways to remove or alter biomass, in this guide we focus primarily on prescribed fire and mechanical manipulation, though we also address targeted grazing and chemical applications. Accordingly, we present a variety of treatment tools and suggestions on where they are most effective in treating forest fuels. Prescribed fire is the preferred method in many settings but can be difficult to implement due to its complexity and risk. A successful prescribed fire is dependent upon factors such as the physical setting, short- and long-term weather, vegetation composition and structure, fuel moisture, and the knowledge and experience of the fire practitioner (Fernandes and Botelho 2003).

There are several excellent fuel treatment syntheses already available that provide general information concerning fuel treatments that does not require repetition in this document. We refer to those documents and highlight the unique aspects and alternative views they provide with regard to dry mixed conifer forests.

The synthesis focuses on providing knowledge associated with fuel treatment planning, implementation, and monitoring. Within a planning framework, this document can inform the process of defining the purpose of and need for a fuel treatment, help in determining where and when a particular fuel treatment needs to be conducted, and assist with integrating other resource objectives into fuel treatments.

Organization and Key Points

The synthesis is organized into three broad sections: ecology of dry mixed conifer forests (Section I), fuel treatment planning and implementation (Section II), and treatment feasibility and effectiveness (Section III). Where relevant, we have inserted manager comments, and inserts with information on related topics.

Section I (Chapters 1 through 5) describes the ecology of dry mixed conifer forests and emphasizes the forest elements that influence fuel treatment planning and implementation. This information can assist in discussions regarding desired forest conditions favoring resilience to fire and other disturbances. To describe the physical and biological setting, we used the LANDFIRE (2008) biophysical setting (BpS) classification system to categorize the various forest types of the dry mixed conifer forests within four broad geographic regions: northern California and Klamath, Pacific Northwest Interior, northern and central Rocky Mountains, and Great Basin (primarily Utah) (Chapter 2). Chapter 3 discusses the suite of disturbances (and their frequency and intensity) that influences the composition and structure of these forests, with some reference to specific areas, such as the Blue Mountains of Oregon and northeastern Washington. Chapter 4 provides a short summary of the management practices (for example, past timber harvests, fire suppression, grazing) that have impacted dry mixed conifer forest characteristics (for example, disturbances, vegetation, soils) and how these changes affect fuel treatment decisions. Chapter 5 is a summary of the current condition of the forests using information from the Pacific Northwest and Interior West Forest Inventory and Analysis (FIA) network http://www.fia.fs.fed.us/regional-offices/.

Key Messages From Section I.

- Dry mixed conifer forests are influenced by multiple disturbances (insects, disease, storms) and contain diverse topography and soils, and when combined, create a diverse set of vegetative compositions and structures.
- Understory vegetation in these forests is diverse and can include grasses, forbs, shrubs and/or trees. Overstory canopies contain a minimum of two tree species, but can have as many as six different coniferous and/or deciduous tree species. Thus, depending on past disturbances, these forests are spatially and temporally diverse and contain many different structural and successional stages.
- Dry mixed conifer forests experience low severity to mixed severity fire regimes. Low severity fire regimes tend to occur in landscapes with nominal topographic relief. Mixed severity fire regimes tend to occur in landscapes with complex topography and an abundance of tree and plant species and disturbances.
- Historical and current use of these forests indicates that these forests are important to society.
- Analysis of current conditions can reveal to what extent certain areas within the dry mixed conifer forests need some type of treatment to address fuel hazards, such as: surface flame lengths (>4 ft), probability of torching (>20 percent), torching index (<20 mph), and mortality (>30 percent). Up to 80 percent of the dry mixed conifer forests contain at least one of these hazard elements and approximately 20 to 30 percent of the Douglas-fir, true fir, pine, and western larch have all four hazard elements.

Section II (Chapters 6 through 10) focuses on the tools, techniques, equipment, and details associated with fuel treatment planning and implementation. This is not a "how-to" section, but rather a description of the steps, conditions, and situations to consider when implementing fuel treatments. In Chapter 6, we provide basic concepts and considerations associated with wildlife habitat relationships, with an introduction to the concepts and questions that are important when manipulating wildlife habitat. Chapter 7 is an overview of the fuel treatment planning process, covering general treatment principles, approaches, opportunities, and challenges. This chapter also discusses how to integrate a variety of objectives into fuel treatment planning. Chapter 8 covers techniques used to implement fuel treatments and discusses mechanical methods, chemical control and targeted grazing. This information is presented in the form of decision-support guides (checklists, flow charts, opportunities) for selecting a fuel treatment technique. Chapter 9 focuses on prescribed fire and discusses basic but important elements of conducting a successful prescribed fire. We include the elements of a burn plan, common oversights in fire planning, factors to consider when implementing a prescribed fire, and unique dry mixed conifer forest situations that may require specific prescribed fire conditions to favor specific outcomes. In interviews, land managers stressed the value of monitoring in fuel treatment programs, but many also acknowledged that they lack the funding or expertise to effectively prepare and implement a monitoring plan. Chapter 10 presents a step-by-step process to aid in the development and implementation of a monitoring program.

Key Messages From Section II.

- Based on our interviews with wildlife biologists, we developed three questions designed to improve communication between vegetation managers and wildlife biologists. The first question is "which habitat elements will the fuel treatments impact and for how long?" To address this question, we provide an expanded definition of plausible wildlife habitat elements, and encourage integration of these elements early in the planning stage. This information provides background to begin addressing the other two questions: "Which wildlife species could be impacted by fuel treatments?" "Will the fuel treatment improve, degrade, or have a neutral impact on the habitat and wildlife species?"
- We propose taking an integrated approach in planning as a plausible method for addressing fuel treatments and other objectives. Integration involves the blending of multiple resources when designing objectives, which can then be used to develop management strategies for treatment placement and design (Stockmann and others 2010). This process promotes communication and mutual learning among different disciplines. The success of using integrated management strategies is dependent on the relationships among the involved managers, the public, and the element of uncertainty associated with ecosystem management.
- Selection of a particular mechanical harvesting or surface fuel treatment depends on several factors including objective, current conditions, and the physical setting. The dry mixed conifer forests offer additional challenges in understory vegetation management. We cover the specific situations and opportunities in which mechanical harvesting, mastication, chemical herbicides, and targeted grazing may provide unique advantages.
- There are a number of steps fire practitioners take before, during, and after ignition of a prescribed fire including burn plan, pre-burn considerations and weather, organization, equipment and communications, and complexity analysis. In addition, there are several unique situations that may benefit from a different approach. When restoring old forests, extra caution and modified burning parameters may be needed to protect individual trees. Killing understory vegetation such as seedlings, saplings, and shrubs may require a particular fire intensity and severity.
- Fuel moisture often dictates prescribed fire outcomes in dry mixed conifer forests, so they are a critical parameter to consider.
- Often there is neither the time nor funds to conduct thorough monitoring of treatment outcomes and longevity. However, time spent on monitoring design is time well spent if it leads to clear objectives and a focused, results-oriented monitoring protocol that can be sustained over time, even as responsibilities for data collection, management, and analysis are transferred among individuals over time.

Section III is intended to be a "reality check," focusing on the challenges and opportunities of fuel treatment implementation. It covers, at least conceptually, what can and cannot be achieved through removal of fuels. In Chapter 11, we provide an evaluation of a set of potential fuel treatments and discuss the economic feasibility and potential for success of each using publicly available data from the U.S. Forest Service's Forest Inventory and Analysis Program, coupled with Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS) and FIA BIOSUM (Biomass Summarization System) computer simulation programs (Fried and others 2005; Reinhardt and Crookston 2003). Chapter 12 addresses the current knowledge regarding fuel treatment longevity and effectiveness.

Key Messages From Section III.

- The economic feasibility of conducting fuel treatments can also offer challenges. Elements of forest and local industry infrastructure (mills, access, and bioenergy) all can dictate whether a particular area is treated. It is not possible to implement a fuel treatment in every place that would benefit from one, and there are many kinds of fuel treatments, only some of which will be effective in any particular stand. There are many stands where no fuel treatment is likely to be effective and many more where an effective treatment will be prohibitively costly. Therefore, it is important to understand the economic reality of treating fuels.
- An understanding of forest fuel treatment longevity and the processes contributing to it are central to a complete evaluation of the effectiveness of treatment alternatives. The changes to fuel structures are a function of pre-treatment condition, post-treatment condition, site productivity, and time. Recognizing the elements that contribute to treatment longevity during the planning process may guide the selection of treatments and treatment combinations.

We also include various appendices to supplement the information presented in some of the chapters. Appendix A presents current conditions using a series of histograms showing the distribution of current fire hazard on forest lands. Appendix B is a list of the variety of decision support tools available, with a short summary and listing of where to find the tools and supporting information on the worldwide web. Appendix C presents the local results from the economic feasibility analysis described in Chapter 11. Managers may want to review our results by region and forest type group, and this appendix will allow them to do so. Appendix D is a list of the Latin terms for the common names of species mentioned in the synthesis. Appendix E provides English to metric unit conversions.

Information Sources

Relevant Literature

For this synthesis, we combed through published materials (journals, U.S. Government documents, symposium proceedings, etc.) that address implementation of specific fuel treatments and consequences for fire behavior and intensity. Nonetheless, we could not review or summarize all of the available literature related to fuel treatments, soil protection, wildlife habitat management, and silviculture, to name a few of the relevant topics. Thus, we selected what we found to be the key literature that fit within the context of the planned objectives and goals of this synthesis. We used several available fuel synthesis documents (including other Joint Fire Science Program syntheses) and provide short summaries of their findings. In these cases, we only cite the synthesis document. When literature specific to dry mixed conifer forests was insufficient to address a particular subject, we also incorporated literature that is relevant to fuel treatments in other forest types (with qualification of the unique attributes of fuel treatments in these forests). In the electronic version of the document, we have provided links to electronic copies of cited literature available in TreeSearch online document library (http://www.treesearch.fs.fed.us/). However, some of the publications have copyright restrictions, and, in these situations, we provide the location where the document can be accessed.

Expert Knowledge

Dry mixed conifer forests cover a broad and diverse region. Therefore, to provide regional and site-specific context to this document, we visited federal, state, and tribal land entities and interviewed over 50 resource specialists in Montana, Idaho, Utah, Washington, Wyoming, Oregon, South Dakota, and California. A specific set of questions guided the discussions between our research team and resource specialists/managers. There were 2 to 10 specialists present during these discussions. The specialists/managers who were interviewed included fire management officers, fuels specialists, wildlife biologists, fuels planners, hydrologists, forest staff officers, silviculturists, and others with shared responsibility for the planning and implementation of fuel treatments at sites within the synthesis area. Comments and discussions generated via this interview process guided both the organization and content of this synthesis. Throughout this document, we provide short summaries of the key points expressed by specialists and managers. We emphasized openness and candor in discussions related to the challenges managers faced during the planning and implementation process; therefore, we have kept all interviewees anonymous. We appreciate the time each person set aside to participate in these discussions.

Through our interviews, managers provided anecdotal information that we considered an important contribution to the knowledge of these forest systems. Some have been included within the chapters and are labeled "Manager's Comment." It is our hope that these valuable insights gained through hard-earned experience may stimulate new ideas or techniques to address comparable problems on similar sites or that they help others address completely different challenges. Comments and questions and subjects expressed through our interviews led to the rationale for each chapter, which is documented at the beginning of several chapters.

Conclusion

Creating fire-resilient ecosystems must be integrated with a range of other forest management objectives and societal needs. Furthermore, a clear understanding of the steps, challenges, opportunities, and feasibility of implementing fuel treatments must also be recognized. All aspects of fuel treatments have their unique challenges and opportunities, but these can be addressed with planning, knowledge, and expertise. Using prescribed fire requires considerable planning and analysis before ignition. Implementing a useful monitoring plan takes time, funding, and commitment. Integrating wildlife habitat has to begin with the first walk through the woods and requires incorporation into a fuel manager's design and planning process. Practical consideration of economic feasibility and available infrastructure (mills and roads) is essential. Continuous communication among disciplines and the public will be part of some fuel treatment planning, and at times there can be considerable confusion in terminology and concepts. It is our hope that this synthesis provides information that will be used for dialogue, mentoring, and understanding the challenges, opportunities, and techniques for incorporating treatments that promote resilient dry mixed conifer forests.

Section I: Ecology of Dry Mixed Conifer Forests









Chapter 2

Potential Vegetation and Biophysical Setting

Introduction

Dry mixed conifer forests can be complex in terms of weather, physical setting, potential vegetation, disturbances, and forest succession. Depending on the combination of these components, multiple tree, shrub, and forb species can be found within stands and across landscapes. These vegetation communities are continually changing in response to the extent and severity of both natural and human caused disturbances (for example, see Arno and others 1997). Because these forests generally occupy transition areas across moisture gradients, they are often adjacent to areas that are relatively drier or wetter. As a result, dry mixed conifer forests occur as part of a mosaic of a diverse set of forest types across the western United States. This chapter describes how we define the dry mixed conifer forests and their distribution within the synthesis area.

Biophysical Settings

The Biophysical Setting Model (BpS) is defined as the types of vegetation communities that could naturally exist based on the current biophysical settings and historic disturbance regimes (LANDFIRE 2008). For a given setting and species mix, forest and plant community development can be relatively predictable, eventually resulting in what is traditionally referred to as climax vegetation. This concept can be used to classify sites and allows for summaries of current vegetation, disturbance regimes, successional pathways, potential vegetation, and other vegetative descriptors relevant to forest development. Although climax vegetation refers to what species could eventually occupy a site, disturbances typically arrest, delay, accelerate, or reset that developmental process, depending on the type and intensity of disturbances. In many areas, the current vegetation will likely be different from the potential vegetation. In a changing climate, we consider these vegetation communities not as static assemblages, but rather a reflection of the environmental setting within which a particular set of species can grow.

Current vegetation can range from shade-intolerant species that occur in open areas during the early stages of stand development (early-seral) to more shade-tolerant species (late-seral) that thrive in closed canopies. However, whether a species is considered early- or late-seral depends on the site where it is growing as well as its associates. For example, although ponderosa pine is generally an early-seral species in dry mixed conifer forests, there are sites where ponderosa pine tends to be late-seral to species such as quaking aspen, paper birch, and pinyon pine. Douglas-fir is another example. Although it is a late-seral species on many ponderosa pine sites, it is frequently an early-seral species, along with western larch and ponderosa pine, when growing on true fir (for example, grand fir or white fir) and western redcedar sites (Mauk and Henderson 1984, Steele and others 1983).

Descriptions of Biophysical Settings

To define the synthesis area consistently, we found it useful to examine the LANDFIRE BpS to see which ones could be considered dry mixed conifer. These groups are diverse, ranging from those that occur on dry sites—where only ponderosa pine and/or Douglas-fir grow—to more moist sites, such as grand fir and even western redcedar habitat types. Many, but not all, include ponderosa pine, and some groups could be considered woodlands rather than forests. Some have shrubby and herbaceous understories, whereas others have sparse understories. They occur within a wide range of elevations, on all aspects, and on slopes ranging from flat to steep.

The descriptions that follow are summarized from the LANDFIRE BpS models. In addition to summaries of vegetation and stand developmental stages, information is given on geographic range, elevation (in numbers or a general description), and the provinces described and mapped by Robert G. Bailey (1994, 1995) (fig. 2.1, table 2.1). The latter are part of a hierarchical description of ecoregions based upon climate, with domain the broadest level, followed by division, and then provinces which represent a more refined subdivision based upon climatic differences (see Bailey [1995] for more details). The descriptions are organized by the following four sub-regions based on the LANDFIRE modeling zones in which they occur: (1) Northern California and Klamath, (2) Pacific Northwest Interior, (3) Northern and Central Rocky Mountains, and (4) Utah. For readers who do not use the BpS models; look for the vegetation description that best aligns with your mixed dry conifer forest.

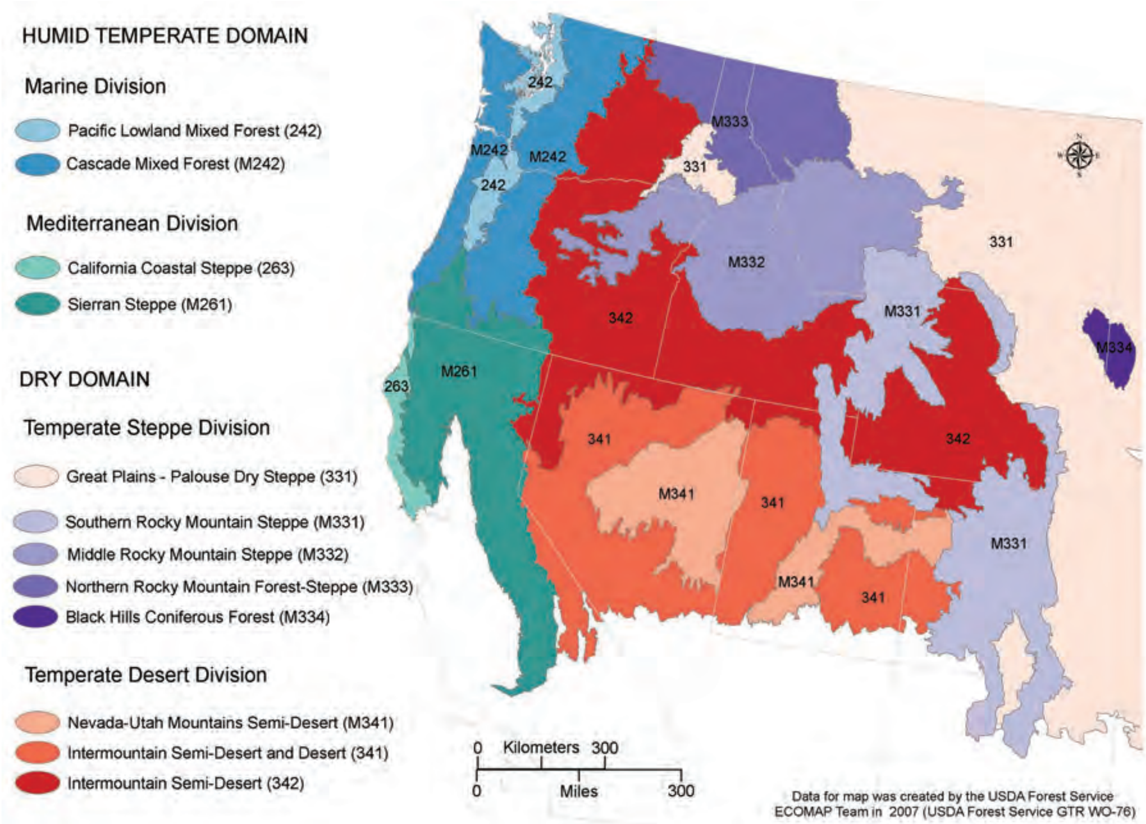

Figure 2.1. Domains, divisions, and provinces within the fuel synthesis area. Domains and divisions are based on climate zones. Provinces (shown on the figure) represent a further refinement of the domains and divisions. The code in parenthesis is labeled on the map. Those beginning with "M" are mountain provinces. Provinces 242 and 342 typically do not contain mixed dry conifer forests although some small isolated areas can be present. See Descriptions of the Ecoregions of the United States (Bailey 1995).

Table 2.1. These are descriptions of general climate, topography, and geology based on Bailey's ecoregions that contain mixed dry conifer forests. Descriptions from: McNab and Avers. 1994. Ecological subregions of the United States. WO-WSA-5. www.fs.fed.us/land/pubs/ecoregions

Province	Climate	Topography	Geology
M242	Maritime; Continental	High mountains; foothills; plateaus; glaciation	Volcanic; basalt; granitic; diorite; andesite; sedimentary; ash; pumice; cinders
263	Mediterranean	Valley bottoms interspersed among ow-elevation long mountain ranges that run parallel in a northwestern direction	Sedimentary rocks
M261	Mediterranean; Continental	Highly dissected by river systems; steep mountains with rounded ridges; narrow canyons; block mountains	Granitic; sedimentary; metamorphic; ultramafic; volcanic
331	Continental	Rolling hills; dissected shale plains; flat-topped buttes; rugged high-elevation mountains; glaciated and non-glaciated areas	Loess, sedimentary rocks; granitic; metasedimentary
M331	Continental	Rugged mountains with rounded ridges; high mountains with sharp crests; high elevation plateaus; broad to narrow valleys; glaciated	Volcanic; gneiss; carbonate; shale; sedimentary; igneous; metasedimentary
M332	Maritime; Continental	Granitic plutons; high, glaciated mountains with narrow valleys; sharp-crested mountains; moderately dissected, uplifted plateau	Loess; volcanic ash; granite; metasedimentary; sedimentary
M333	Maritime; Continental	High rugged mountains; rounded mountains; steep dissected mountains; glaciation	Igneous; sedimentary; metamorphic; metasedimentary; loess; volcanic ash
M334	Continental	Dissected mountains; unglaciated	Granitic; limestone plateau; sedimentary
M341	Continental	High plateaus; north-south mountains separated by broad sediment-filled valleys	Folded and faulted sedimentary; volcanic rocks
341	Continental	North-south trending mountains are separated by broad sediment-filled valleys	Lower Tertiary volcanic rock with Miocene volcanic rock. Quaternary deposits in valleys.

Northern California and Klamath

Many of the vegetation descriptions occur in more than one of our sub-regions; therefore, the descriptions we describe within a given sub-region can occur in other locations within our synthesis area. Figure 2.2 shows the distribution of the dry mixed conifer forests within the northern California and Klamath sub-region.

Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland (10210)
Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland (10220)

Geographic area: northern California and southwestern Oregon
Elevation: 1200-4500 ft for BpS 10210; >4500 ft for BpS 10220
Provinces: Mostly in M261, but small pockets can occur in 242 and 263

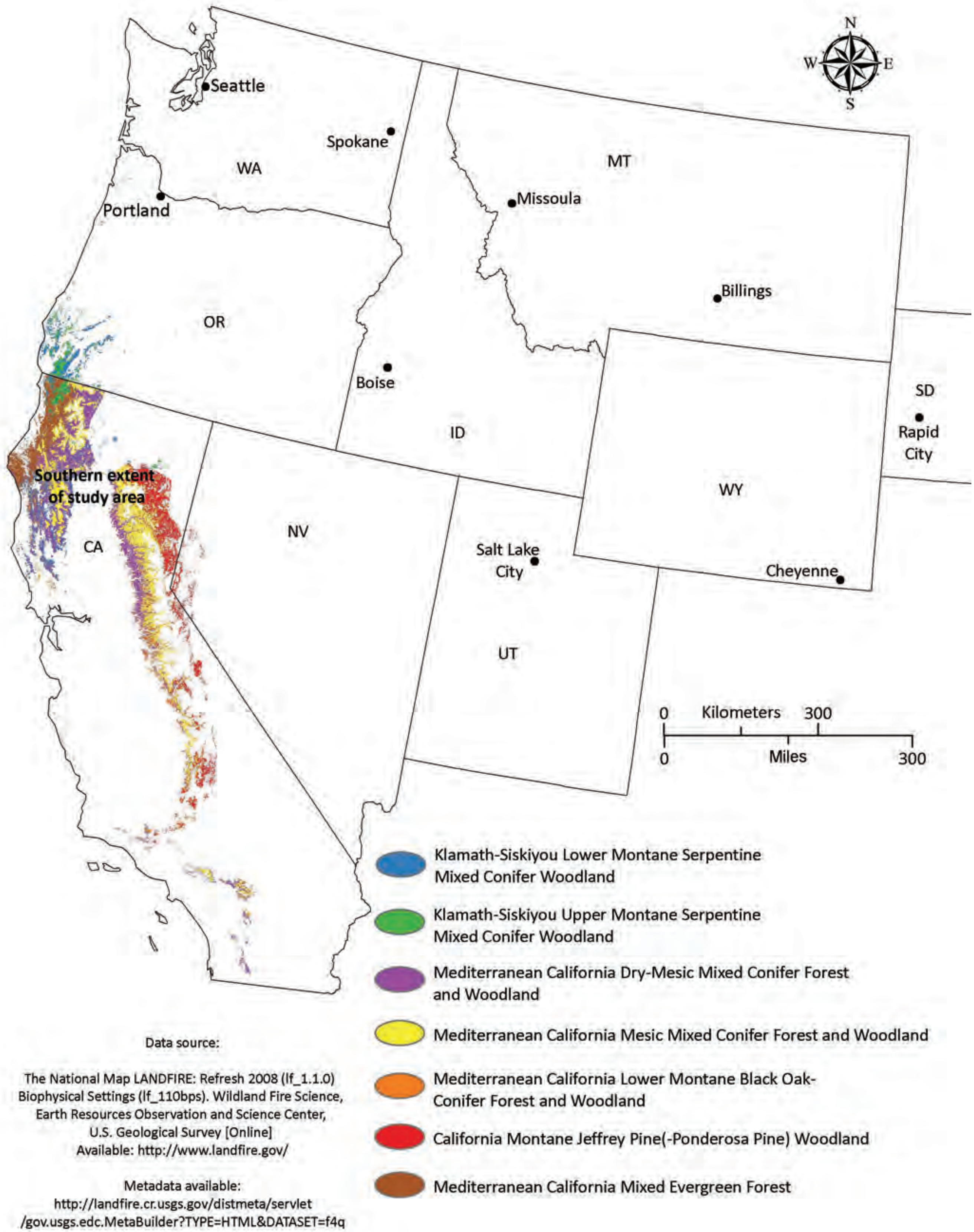

Figure 2.2. Distribution of the biophysical settings (BpS) for northern California and Klamath.

These types have limited distribution, occurring on ultramafic soils. A wide variety of tree species can be present, including Douglas-fir, incense cedar, sugar pine, western white pine, Jeffrey pine, and Port Orford cedar. Shrub species include oaks, dwarf silktassel, western azalea, California buckthorn, and buckbrush (table 2.2).

The early developmental stage is dominated by grasses, shrubs, and tanoak, Douglas-fir, incense cedar, and canyon live oak seedlings and saplings. As the stand develops, canopy cover increases to over 50 percent, unless fires occur frequently or if the particular site is less productive. As the stand ages, large trees are present, but not as many or as large as in other more productive mixed conifer sites. Douglas-fir and incense cedar occur in all stories and tanoak and canyon live oak dominate the low to mid canopy positions.

The difference between BpS 10210 and 10220 is based on elevation and the presence of Shasta red fir in the latter. Otherwise, the models are the same.

Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland (10270)

Geographic area: California and southern Oregon
Elevation: 2000-5900 ft in northern California; 4000-7000 ft in southern Oregon
Provinces: 263, M261, and some in M242 and 263

At lower elevations this BpS may be adjacent to woodlands and grasslands and at upper elevations next to mesic mixed conifer. Unlike the mesic mixed conifer type, this BpS does not have white fir. Douglas-fir, ponderosa pine, and incense cedar are the most common conifer tree species that are co-dominants in the overstory (table 2.2). Others that may be present include Jeffrey pine, knobcone pine, and sugar pine. In the lower canopy, California black oak and canyon live oak are common, and Pacific madrone is common in southern Oregon. Understory shrubs include poison oak, ceanothus, currant, barberry, ocean spray, and many other species.

Early development is dominated by grasses, shrubs, and Douglas-fir, ponderosa pine, and sugar pine seedlings/saplings. As the stand develops and the canopy closes, pole- to medium-sized ponderosa pine, Douglas-fir, incense cedar, and sugar pine dominate the overstory, with California black oak in the mid-story. The typical successional pathway, driven by frequent low-intensity fires, leads to open stands dominated by ponderosa pine, Douglas-fir, and various hardwoods. Longer intervals between fires (30 years) lead to crowded conifer stands with hardwoods in the understory. In some sites, Douglas-fir is able to recruit beneath the larger ponderosa pine and Douglas-fir. These kinds of stands are composed of ladder fuels, creating the potential for the initiation of crown fires.

Mediterranean California Mesic Mixed Conifer Forest and Woodland (10280)

Geographic area: California, southern Oregon
Elevation: 2400-3000 ft in the Sierra Nevada and 3800-6700 ft in the Klamath Mountains
Provinces: M242, M261

This BpS is similar to 10270 (the preceding BpS just described above), except that it has white fir. During the early stages of stand development, Douglas-fir, ponderosa pine, and sugar pine are in the overstory, with white fir in the overstory and mid-story (table 2.2). Sometimes a continuous canopy may develop from seedlings, whereas other times shrubby conditions can persist for long periods of time, composed of ceanothus species, greenleaf manzanita, ocean spray, and other species. Hardwood sprouting from Pacific madrone, chinquapin, tanoak, and live oak can be significant.

Table 2.2. Biophysical setting models from the LANDFIRE project (2008) for Northern California and Klamath.

	Northern California and Klamath				
Biophysical setting	**Dominant species[1]**	**Early seral species[1]**	**Late seral species[1] Open stands**	**Late seral species[1] Closed stands**	**Shrub species**
Klamath-Siskiyou Montane Serpentine Mixed Conifer Woodland (lower and upper)	Douglas-fir, incense cedar, Port Orford cedar, Jeffrey pine, western white pine, tanoak	tanoak, Douglas-fir, incense cedar, canyon live oak	tanoak, Douglas-fir, incense cedar, canyon live oak	tanoak, Douglas-fir, incense cedar, canyon live oak	huckleberry oak, dwarf silktassel, deer oak, pinemat manzanita, western azalea, Pacific poison oak, California buckthorn, greenleaf manzanita, buckbrush
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	Douglas-fir, ponderosa pine, incense cedar, California black oak, sugar pine	Douglas-fir, ponderosa pine, sugar pine	ponderosa pine, Douglas-fir, incense cedar, California black oak	ponderosa pine, Douglas-fir, incense cedar, California black oak	Pacific poison oak, deerbrush, snowbrush ceanothus, sticky whiteleaf manzanita, barberry, creeping snowberry
Mediterranean California Mesic Mixed Conifer Forest and Woodland	white fir, Douglas-fir, sugar pine, ponderosa pine	Douglas-fir, ponderosa pine, sugar pine, white fir	white fir, ponderosa pine, sugar pine, Douglas-fir	white fir, Douglas-fir, ponderosa pine, sugar pine,	hazelnut, Pacific dogwood, bush chinquapin, greenleaf manzanita, ceanothus species
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	California black oak, canyon live oak, ponderosa pine, Douglas-fir, tanoak, pacific madrone	California black oak, canyon live oak	N/A	N/A	whiteleaf manzanita, ceanothus species, Pacific poison oak
California Montane Jeffrey Pine (-Ponderosa Pine) Woodland	Jeffrey pine, ponderosa pine	Jeffrey pine	Jeffrey pine	Jeffrey pine, white fir	bitterbrush, manzanita, ceanothus species
Mediterranean California Mixed Evergreen Forest	Douglas-fir, tanoak, Pacific madrone, canyon live oak, sugar pine	tanoak, Pacific madrone, canyon live oak, Douglas-fir	N/A	Douglas-fir, tanoak, Pacific madrone, canyon live oak	hazelnut, California huckleberry, Pacific rhododendron, salal, Pacific poison oak

[1]Tree species are in order of dominance.

When trees dominate the early stages rather than shrubs, the stand can develop into pole- to medium-sized conifers with >50 percent canopy cover, along with the decline of shrubs and herbaceous species. These dense stands are susceptible to insects and diseases. Frequent surface fires can maintain more open conditions during the mid-developmental stages. Open conditions also favor the hardwoods present in the understory. When disturbances occur less often, white fir may begin to dominate the stand. In later developmental stages, patches of relatively open canopies (<50 percent) occur on southerly aspects and ridgetops. Open late seral stands may persist for hundreds of years in a matrix across eastern and northwestern aspects. In more closed conditions (canopy >50 percent), patches occur on northern aspects and lower slope positions, with an understory filled with shade-tolerant species (primarily white fir).

Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland (10300)

Geographic area: Coast Range, Klamath Mountains of California and Oregon, and lower slopes of the western Sierras
Elevation: 1200-4850 ft
Provinces: M261, 263, and some in 242

Ponderosa pine and oaks such as California black oak and canyon live oak, along with Douglas-fir, characterize this BpS. The oaks will form a dense canopy below the conifers dominated by California black oak. Common shrubs in the understory include whiteleaf manzanita, ceanothus species (for example, buckbrush), and Pacific poison oak. Grasses that occur, although not as commonly occurring as shrubs, include California and Idaho fescue (table 2.2).

Early stages of stand development following a disturbance consist of coppicing oak sprouts. Pacific poison oak may also be abundant, along with bunch grasses and forbs. Some sites will have ponderosa pine and Douglas-fir up to six inches in diameter. After about 25 years, this stage may succeed to a mid-developmental open stage, unless surface fires and browsing from herbivores maintain this early successional stage. Areas that do not experience these disturbances will develop into mid-developmental closed stages that may have a dense canopy of oak and conifers in the upper canopy position, with sod-forming grasses and shade-tolerant shrubs in the understory. Mid-seral open stands will be dominated by hardwoods, with a more sporadic occurrence of conifers compared to the closed-canopy stage; bunchgrasses and shrubs will be in the understory. Oak diameters can range from 8–30 inches.

California Montane Jeffrey Pine (-Ponderosa Pine) Woodland (10310)

Geographic area: northern California and southern Oregon
Elevation: 2500-3500 ft
Provinces: Mostly in M261 but some in M242 and 341

Jeffrey pine dominates this BpS, but ponderosa pine can also be a dominant tree species (table 2.2); white fir occurs as a codominant in closed developmental stages, in the absence of fire. A substantial shrub community is present in the understory that includes mountain big sagebrush, bitterbrush, greenleaf manzanita, snowbrush ceanothus, and in more mesic sites, snowberry.

The early developmental stage is dominated by fire-dependent shrubs, perennial bunch grasses, forbs, and Jeffrey pine seedlings. When fires are infrequent enough to thin small trees and a shrub layer does not develop, this stage will transition into a closed, mid-developmental stage. With the continued absence of fire, the closed, mid-developmental stage transitions into a closed, late-developmental stage consisting of a dense stand of medium- to large-diameter Jeffrey pine and white fir co-dominating the overstory, with white fir in the understory. This condition is characterized by within-stand mortality and surface and ladder fuel accumulation. However, in areas that do experience low intensity surface fires, the early developmental stage transitions into an open, mid-developmental stage. The open, mid-developmental stage consists of pole- to medium-sized Jeffrey pines along with a shrub layer. As the stand grows and low intensity fires are allowed to continue, the open, late-developmental stage emerges, consisting of large Jeffrey pines with scattered shrubs, forbs, and grasses; surface fuels are scarce due to frequent surface fires.

Mediterranean California Mixed Evergreen Forest (10430)

Geographic area: northern California Coast Range, southern Oregon coast, and Klamath-Siskiyou Mountains
Elevation: Mostly below 3500 ft but can be up to 4000 ft
Provinces: 263, M242, M261, and some in 242

This BpS occurs on all aspects, and although it is influenced by maritime climates, does not occur on the coast itself. Douglas-fir and sugar pine grow alongside hardwoods such as tanoak, Pacific madrone, canyon live oak, California black oak, and California laurel (table 2.2).

The early developmental stage is a mixture of thickets of sprouting hardwoods and sprouting shrubs such as Oregon grape, salal, rhododendron, and ceanothus, with some Douglas-fir. Tanoak usually will dominate. After about 25 years, the Douglas-fir seedlings begin to emerge from the dense thickets of hardwoods and shrubs and share the upper story with tanoak, canyon live oak, and Pacific madrone. Later developmental stages can have trees with diameters >30 inches; sugar pines may be present. Because of the epicormic sprouting of the hardwoods and shrubs, any moderate or high severity fire disturbance promotes the development of a hardwood-dominated stand, whereas low severity fires favor the dominance of Douglas-fir and other conifers.

Pacific Northwest Interior

There are four primary vegetation descriptions within the dry mixed conifer forests of the Pacific Northwest Interior. Figure 2.3 illustrates the distribution of these characterizations.

East Cascades Mesic Montane Mixed-Conifer Forest and Woodland (10180)

Geographic area: maritime-influenced sites in the eastern Cascades in Washington
Elevation: low to mid elevation slopes
Provinces: Mostly in M242, but some in 242 and M261

Historically, this BpS had much higher proportions of western white pine and western larch than what is present today. Currently, these stands are dominated by western hemlock, grand fir, and Douglas-fir. Other species present include western larch, western white pine, western redcedar, and Engelmann spruce (table 2.3). In the drier portions of this BpS, ponderosa pine is important. Understory species include vine maple, currant, thimbleberry, and queen cup beadlily.

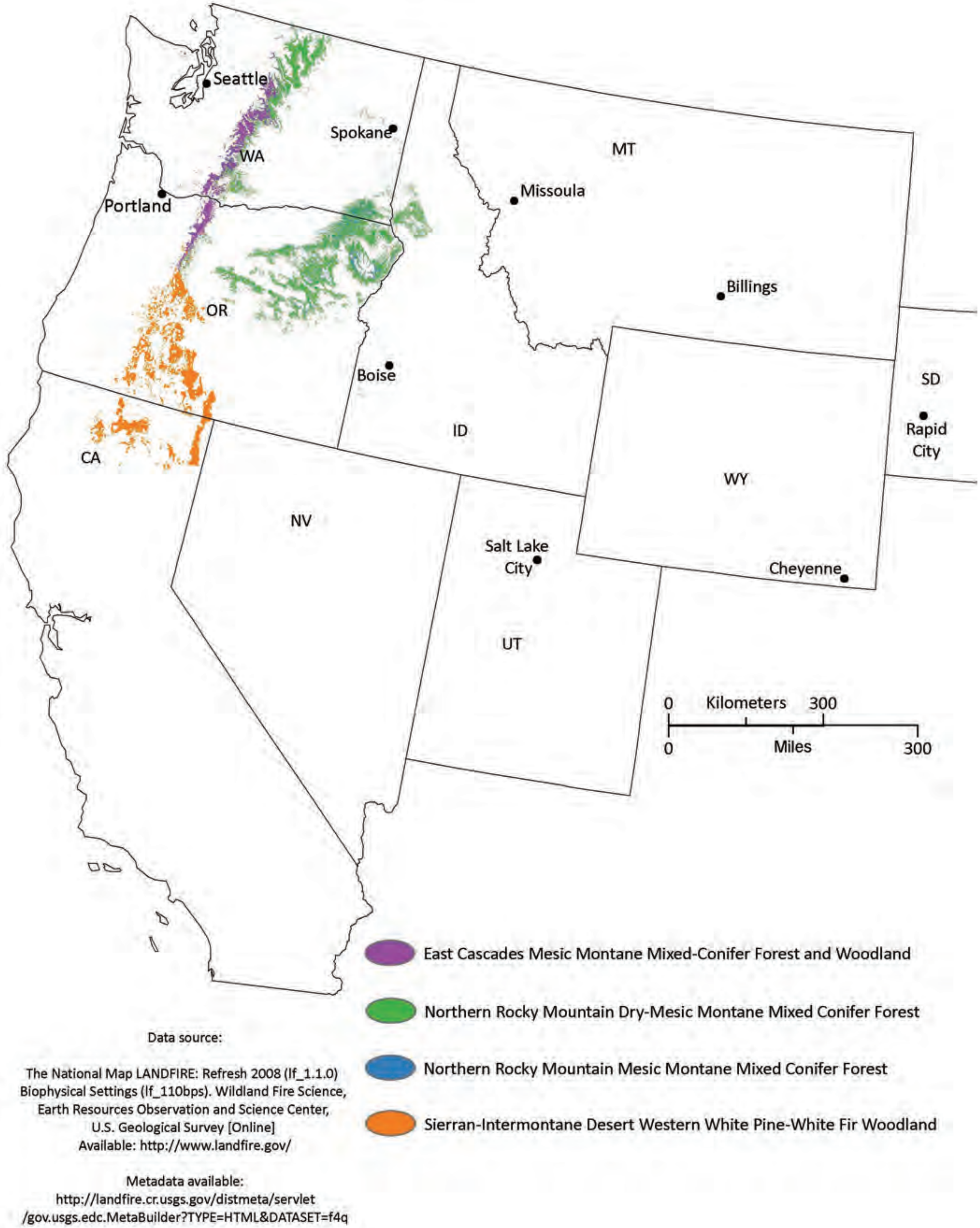

Figure 2.3. Distribution of the biophysical settings (BpS) for Pacific Northwest Interior.

Table 2.3. Biophysical setting models from the LANDFIRE project (2008) for the Pacific Northwest Interior.

	Interior Pacific Northwest				
Biophysical setting	**Dominant species**[1]	**Early seral species**[1]	**Late seral species**[1] **Open stands**	**Late seral species**[1] **Closed stands**	**Shrub species**
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	Douglas-fir, grand fir, western hemlock, western redcedar, western white pine, western larch, Engelmann spruce, lodgepole pine	Douglas-fir, western larch, western white pine	western white pine, western larch, western redcedar, grand fir	western redcedar, western hemlock, Douglas-fir, grand fir	vine maple, thimbleberry, currant, thinleaf huckleberry
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	ponderosa pine, grand fir, Douglas-fir, white fir (in southern Oregon)	ponderosa pine, Douglas-fir, western larch	ponderosa pine, Douglas-fir, western larch, grand fir	ponderosa pine, Douglas-fir, grand fir, western larch	Early: ceanothus species, Scouler's willow Late: snowberry, rose, mountain mahogany
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	grand fir, Douglas-fir, ponderosa pine, western larch	See shrub species	Douglas-fir, ponderosa pine, western larch, grand fir	grand fir, Douglas-fir, ponderosa pine, western larch	Early: ceanothus, manzanita, vine maple, ninebark
Sierran-Intermontane Desert Western White Pine-White Fir Woodland	western white pine, white fir, ponderosa pine	western white pine, ponderosa pine, white fir	western white pine, white fir, ponderosa pine	white fir, ponderosa pine	greenleaf manzanita, pinemat manzanita, bush chinquapin, ceanothus species, sticky currant

[1]Tree species are in order of dominance.

Early stages of development after a fire are dominated by shrubs such as vine maple, thimbleberry, currant, and thinleaf huckleberry; some tree seedling and saplings are also present. Eventually, the trees will overtop the shrubs and canopy cover will become dense, with Douglas-fir, western larch, grand fir, and western pine in the overstory, and western redcedar in the understory. However, disturbances can create patches of open areas that favor western larch and western white pine. In later developmental stages, open canopy conditions are uncommon. In open, patchy conditions, several tree species will be co-dominant, including both early and late seral species. Without disturbances such as mixed severity fires that create these openings, multi-story dense canopy conditions will develop with a depauperate understory. Because of mortality from in-stand competition and diseases such as root rot, large woody debris is abundant. Replacement fires can occur in this BpS, as well as other weather-related disturbances, that will set the stand back to early developmental open conditions. Otherwise, mixed severity fires will maintain the stand in late developmental open or closed stages.

Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest (10450)

Geographic area: Oregon, Washington (more detail below)
Elevation: 2000-6000 ft (most of these stands occur between 3000 and 4500 ft)
Provinces: M242, M261, 331, M332, M333
Notes: Dry upland forest Potential Vegetation Group (PVG); Warm dry Plant Association Group (PAG); plant associations include Douglas-fir/elk sedge, Douglas-fir/pinegrass, Douglas-fir/snowberry, Douglas-fir/ninebark, grand fir/elk sedge, and grand fir/pinegrass (Powell and others 2007).

This BpS occurs on the eastern side of the Cascades in Oregon and Washington, the Blue Mountains of Oregon and Washington, the Ochoco Mountains of central Oregon, and the Wallowa-Snake province of Oregon and Washington. It occurs just above ponderosa type forests and below fir-dominated, mesic, mixed conifer forest types. Conifers present are ponderosa pine (often the dominant species), grand fir, Douglas-fir, and western larch (table 2.3); Douglas-fir dominates the dry areas in the northern portions. Grand fir is less frequent in the northern portion (near Wenatchee, Washington) and white fir occurs in southeastern Oregon.

The early developmental stage is dominated by open stands of ponderosa pine, Douglas-fir, and larch seedlings/saplings. These trees are often mixed with grasses, sedges (for example, Geyer's sedge), and shrubs such as ceanothus and Scouler's willow. In the absence of disturbances, dense stands develop consisting of 5 to 20 inch ponderosa pine in the upper story and Douglas-fir and western larch in the mid-to-upper story. Open stands with the same tree diameter range and species composition often occur, with understories consisting of snowberry, rose, mountain mahogany, arnica, and lupine. In the late stages of stand development, both open-canopy forests and dense forests will have trees with diameters exceeding 20 inches. The difference is that the dense forests will have a sparse understory (not as shrub dominated as the open canopy forests) (table 2.3). Grand fir will often be present in the mid-to-upper canopy.

Northern Rocky Mountain Mesic Montane Mixed Conifer Forest (10470)

Geographic area: Oregon and Washington
Elevation: 1000-5000 ft
Provinces: M332, M333

This BpS is found on the eastern side of the Cascades in Oregon and Washington, the Blue Mountains of Oregon and Washington, the Ochoco Mountains of central Oregon, and the Wallowa-Snake province of Oregon and Washington. In the Blue Mountains, it occurs above pine-dominated, dry mixed conifer types and below subalpine fir. In the Cascades, it occurs below silver fir/western hemlock or mountain hemlock types. A mixture of conifers such as grand fir, white fir, and Douglas-fir can occur, along with various amounts of other conifers such as western larch, ponderosa pine, lodgepole pine, and Engelmann spruce (table 2.3). In areas north of McKenzie Pass, Oregon, grand fir replaces white fir and no western larch is found south of Bend, Oregon.

Shrubs dominate early development. In the Cascade region, snowbrush ceanothus, manzanita, and Cascade barberry are important. In the Blue Mountains, Rocky Mountain maple, snowbrush ceanothus, and mallow ninebark are important. Although some areas may persist as shrubfields for long periods of time, usually within 30 years or so a mixture of shade-tolerant and shade-intolerant conifers will begin to dominate the closed, mid-developmental stage. Although Douglas-fir and/or grand fir often dominate, ponderosa pine, western larch, western white pine, and lodgepole pine can be present. This stage has prolific regeneration and in the absence of disturbance can transition into a closed, late developmental stand within 70 years. However, if insect, disease, or fire occurs during the closed, mid-developmental stage, the stand will transition into an open, mid-developmental stage dominated by shade-intolerant species such as ponderosa pine and western larch, with some Douglas-fir and/or grand fir present. This stage is either multi-storied or single-storied. Mixed severity fires govern maintenance of this stage. Insects and disease target the older and large trees and can cause a transition back to an open, mid-developmental stage. Without disturbances, this stage can persist for 50 years before transitioning to a closed, late developmental stand with multiple canopies, large diameter grand fir and Douglas-fir, and some ponderosa pine and western larch. Fire transitions this stage back to an open, late developmental stand. Insects and disease return the stage to an open, mid- or late-developmental stand, depending on the disturbance factor.

Sierran-Intermontane Desert Western White Pine-White Fir Woodland (11720)

Geographic area: northern California and southwestern Oregon (northern Sierra Nevada, east into the Modoc Plateau).
Elevation: 4,500–7,000 ft
Provinces: M242, M261

This BpS occurs just above the montane ponderosa pine zone. This system is somewhat in the rainshadow of the Sierras and Cascades and thus has a continental regime. Western white pine is most often the dominant tree species, but white fir and ponderosa pine are often present. Although shrub cover is sparse, the species that are present include greenleaf and pinemat manzanita, bush chinquapin, ceanothus species, and sticky currant (table 2.3); herbaceous species, also sparse, include heartleaf arnica and various grass and sedge species.

Tree seedlings mixed with shrubs and grasses characterize early stages of stand development; usually, ceanothus species will be present. Replacement fires may maintain a shrub-dominated stand that can persist for decades. In the absence of fire, closed stands of 5 to 20 inch diameter trees will develop, but rarely will exceed 80 percent canopy closure. These stands have a higher probability of mixed severity fire than the more open stands because of a denser understory; mixed severity and surface fires will maintain more open conditions. As stands age, open or closed conditions depend on how often fires occur. Late developmental open stands transition to closed stands if fire does not occur for 30 years. Closed stands are more likely to have mixed severity fires, surface fires are less common, and other disturbances such as insects/diseases play a role; competition between species in dense stands is also important.

Northern and Central Rocky Mountains

There were eight vegetation descriptions identified for this sub-region. Figure 2.4 shows their distribution. They include types dominated by ponderosa pine and Douglas-fir, western larch, and grand fir.

Northern Rocky Mountain Dry-Mesic Montane Mixed Forest – Ponderosa Pine-Douglas-fir (10451)

Geographic area: northern Idaho, western Montana, and eastern Washington, extending south into the Great Basin
Elevation: 2500 to over 4000 ft
Provinces: 331, M332, M333
Notes: Potential Vegetation Types (PVT) include Douglas-fir warm dry type 1, Douglas-fir moist type 2, Douglas-fir cool dry type 3, and grand fir dry type 1 (USDA Forest Service, Northern Region 2004).

In this BpS, ponderosa pine dominates dry sites on southerly aspects, whereas Douglas-fir tends to be dominant on northerly aspects. On mesic sites and in the absence of fire, Douglas-fir often can be a co-dominant in the upper canopy. Shrubs and grasses are prevalent through all stages of stand development. At lower elevations and on southerly aspects, this BpS occurs next to dry ponderosa pine and shrub systems. At higher elevations and on northerly aspects, it occurs next to systems with western larch, grand fir, and subalpine fir.

Stand development begins with shrubs such as ninebark and ceanothus dominating, along with ponderosa pine, western larch, Douglas-fir, and lodgepole pine seedlings and saplings; sedges and pine grass may also be present. As the stand develops and the canopy closes, sapling and pole-sized ponderosa pine and Douglas-fir dominate; western larch abundance will decrease and grand fir will remain or increase because of its tolerance to shade. In open mid developmental stages, shrubs such as ninebark, ceanothus, and spiraea will be dominant in the understory, along with elk sedge and pinegrass. Ponderosa pine and Douglas-fir dominate the later developmental open and closed stages; grand fir will be present in the mid-story in late developmental closed stands (table 2.4).

Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest – Western Larch (10452)

Geographic area: northern Idaho and western Montana
Elevation: 3000-6000 ft
Provinces: M332, M333
Notes: Potential Vegetation Types (PVT) include grand fir wet type 3, subalpine fir moist type 2, and Douglas-fir moist type 2 (USDA Forest Service, Northern Region 2004).

This BpS occurs primarily on northerly aspects and includes Douglas-fir, lodgepole pine, and some ponderosa in the overstory along with western larch. In the absence of fire, Engelmann spruce and subalpine fir may also be present. Shrubs in the understory usually include huckleberry, twinflower, Sitka alder, and mallow ninebark (table 2.4).

Although western larch is usually dominant during the early stages of stand development, lodgepole pine and Douglas-fir may also occur in the upper canopy position, with subalpine fir beneath. As the stand develops, western larch continues to dominate, with other species present as co-dominants. During this stage, Douglas-fir may increase in the understory if there are no disturbances. In the later stages, if disturbances do occur, openings are created in the canopy favoring large western larch and Douglas-fir while reducing the abundance of subalpine fir, grand fir, and lodgepole pine.

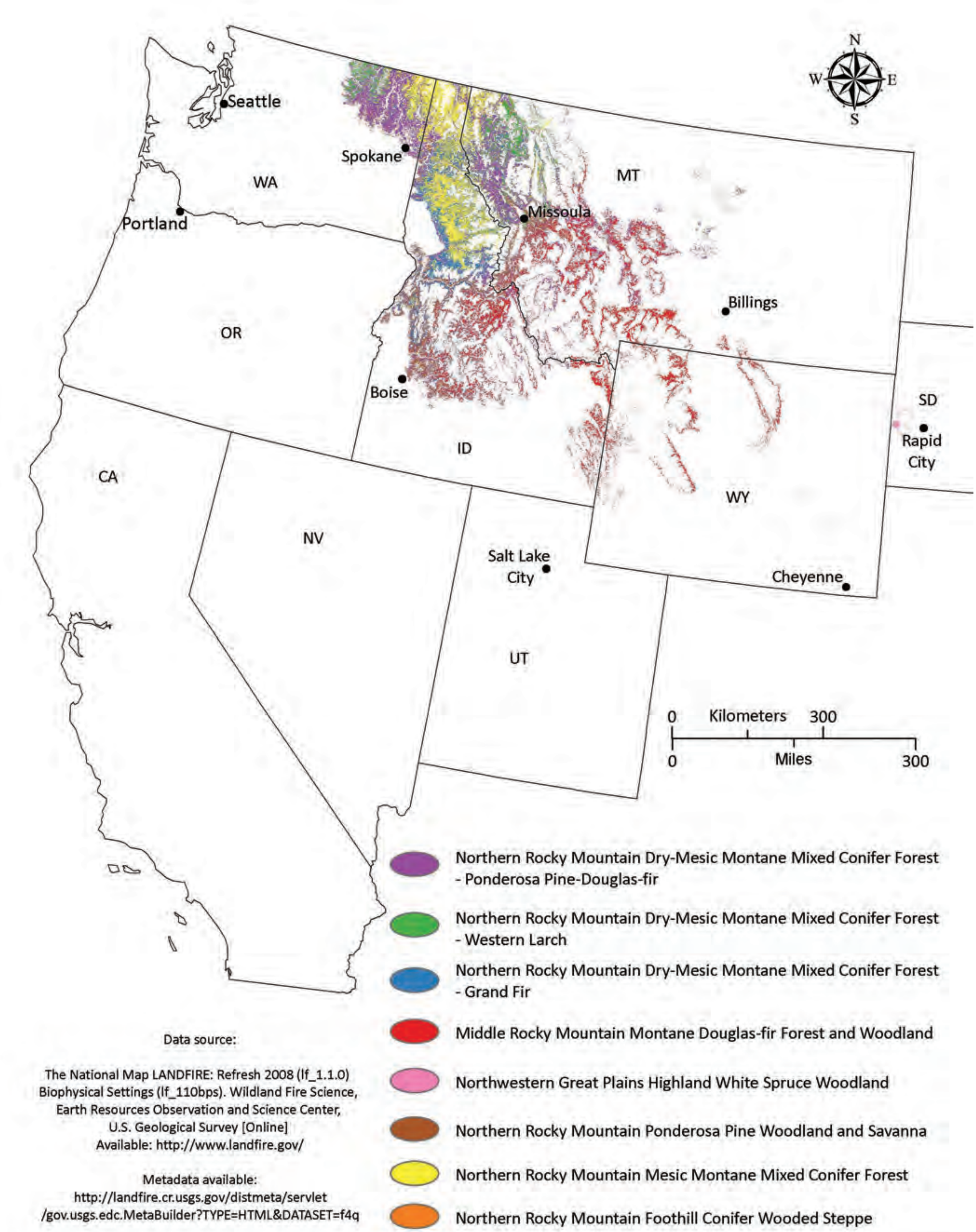

Figure 2.4. Distribution of the biophysical settings (BpS) for the northern and central Rocky Mountains.

Table 2.4. Biophysical setting models from the LANDFIRE project (2008) for the Northern and Central Rocky Mountains.

	North and Central Rocky Mountains				
Biophysical setting	**Dominant species[1]**	**Early seral species[1]**	**Late seral species[1] Open stands**	**Late seral species[1] Closed stands**	**Shrub species**
Northern Rocky Mountain Dry-Mesic Montane Mixed Forest – Ponderosa Pine-Douglas-fir	ponderosa pine, Douglas-fir, lodgepole pine, grand fir, western larch	ponderosa pine, lodgepole pine, western larch, Douglas-fir	ponderosa pine, Douglas-fir, western larch	ponderosa pine, Douglas-fir, grand fir, western larch	ceanothus species, mallow ninebark, spiraea, Scouler's willow, ocean spray
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest – Western Larch	western larch, lodgepole pine, Douglas-fir, subalpine fir	western larch, lodgepole pine, Douglas-fir, subalpine fir	western larch, Douglas-fir, lodgepole pine, ponderosa pine	subalpine fir, Douglas-fir, western larch, grand fir	thinleaf huckleberry, twinflower, Sitka alder, ninebark
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest – Grand Fir	lodgepole pine, Douglas-fir, western larch, grand fir	lodgepole pine, Douglas-fir, lodgepole pine	western larch, Douglas-fir, ponderosa pine	western larch, grand fir, Douglas-fir, lodgepole pine	mountain huckleberry, grouse whortleberry, serviceberry, snowberry
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	Douglas-fir, lodgepole pine, limber pine	Douglas-fir, lodgepole pine, limber pine	Douglas-fir, lodgepole pine, limber pine	Douglas-fir, lodgepole pine, limber pine	Shrubs are sparse-not listed in the biophysical setting model description
Northwestern Great Plains Highland White Spruce Woodland	ponderosa pine, white spruce	quaking aspen, paper birch	ponderosa pine, white spruce, quaking aspen, paper birch	ponderosa pine, white spruce	bearberry, serviceberry
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	ponderosa pine	ponderosa pine	ponderosa pine, Douglas-fir	ponderosa pine, Douglas-fir	common snowberry, antelope bitterbrush, chokecherry, mountain mahogany
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	western white pine, western larch, Douglas-fir, grand fir, western redcedar, western hemlock	western white pine, western larch	western white pine, western larch, western redcedar, grand fir	western redcedar, western hemlock, Douglas-fir, grand fir	snowbrush ceanothus, Scouler's willow, thinleaf alder, Rocky Mountain maple, spiraea, thimbleberry, big huckleberry
Northern Rocky Mountain Foothill Conifer Wooded Steppe	Douglas-fir, ponderosa pine, limber pine, Rocky Mountain juniper	Douglas-fir, limber pine	Douglas-fir, limber pine	N/A	mountain big sagebrush, common juniper

[1]Tree species are in order of dominance.

If disturbances are absent, large western larch and Douglas-fir will still dominate the overstory, with subalpine fir present in the mid-story and understory. At later stages in stand development, lodgepole pine is no longer present in high numbers.

Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest – Grand Fir (10453)

Geographic area: Idaho, western Montana, eastern Oregon, eastern Washington.
Elevation: Above 4500 ft
Provinces: M332, M333
Notes: Potential Vegetation Types (PVT) include grand fir moist type 2; includes warm/moderately moist grand fir habitat types such as grand fir/twinflower (ABGR/CLUN) and grand fir/wild ginger (ABGR/ASCA) (USDA Forest Service, Northern Region 2004).

Lodgepole pine and western larch dominate the forests in this BpS, with lesser amounts of grand fir, ponderosa pine, and Engelmann spruce. In the absence of disturbances, grand fir increases in the understory during mid to late successional stages. Understory species include beargrass, mountain huckleberry, serviceberry, and snowberry (table 2.4).

Forbs and shrubs dominate the early stage of stand development before transitioning to a seedling and sapling stage dominated by lodgepole pine, with Douglas-fir and western larch common; ponderosa pine and grand fir are less common. Between 30 and 100 years, pole-sized lodgepole pines begin to dominate, along with Douglas-fir and western larch as secondary dominants in closed-canopy stands. As stands continue to develop and mature, species dominance will depend on the creation of canopy openings from fire, insects, or disease. Open-canopy stands are dominated by western larch and Douglas-fir, with some residual ponderosa pine, grand fir, and lodgepole pine also present. In mature forests, whether open or closed, western larch is often the dominant overstory species. However, other species may also be dominant or secondary dominants, depending on whether the canopy is open or closed. For example, grand fir can dominate closed canopies and Douglas-fir can dominate those that are more open.

Middle Rocky Mountain Montane Douglas-fir Forest and Woodland (11660)

Geographic area: eastern Idaho, southwestern Montana, and northwestern Wyoming
Elevation: Lower foothills, above grasslands and shrublands
Provinces: 331, M331, M332, M333
Notes: Potential Vegetation Types (PVT) include Douglas-fir moist type 2 and Douglas-fir cool dry type 3; includes dry Douglas-fir habitat types such as Douglas-fir/ninebark (PSME/PHMA) and Douglas-fir/snowberry (PSME/SYAL) (USDA Forest Service, Northern Region 2004).

This BpS occurs on an ecotone with grasslands and shrublands below and dry subalpine fir above. Stands are open and dominated by large Douglas-fir, with a presence of limber pine and, lodgepole pine (in cooler locations). Some areas have quaking aspen and other areas can have ponderosa pine occurring as an incidental species. Shrub cover in the understory is often sparse, consisting of juniper species and mountain big sagebrush. In some areas, however, shrub cover can be denser and be composed of species such as snowberry and ninebark. Important graminoids include pinegrass and Idaho fescue (table 2.4).

Early stages of stand development consist of Douglas-fir seedlings and saplings (quaking aspen, limber pine, and ponderosa pine may also be present), bunchgrasses, and shrubs. Over time, in the absence of disturbance, the density of pole-sized Douglas-fir will increase at the expense of shrubs such as sagebrush. Surface fire, however, will keep the stand open, allowing sagebrush and bunchgrasses to persist along with the trees.

As long as these conditions continue to occur, the open canopy persists, allowing the development of medium-to-large diameter trees along with an understory of sagebrush and bunchgrass. Without surface fires, a closed-canopy, multistoried forest with a sparse understory will develop that is susceptible to mixed severity fires.

Northwestern Great Plains Highland White Spruce Woodland (10480)

Geographic area: northeastern Wyoming and western South Dakota (Black Hills)
Elevation: 5700-6000 ft
Provinces: M334

This BpS represents the white spruce habitat type (Hoffman and Alexander 1987). Ponderosa pine, white spruce, paper birch, and aspen dominate the overstory. Northern aspects and higher elevation areas are dominated by white spruce and paper birch, whereas ponderosa pine dominates the southern aspects and lower elevations. Shrub species include bearberry, serviceberry, and snowberry (table 2.4). Mountain grasslands are dispersed throughout, which influences burn patterns.

Stand development begins with a mixture of quaking aspen, paper birch, shrubs, and a dense herbaceous cover of forbs. As the stand develops and the canopy closes, paper birch becomes dominant on northern aspects and moist slopes, with quaking aspen on the remaining sites. With time, ponderosa pine and white spruce develop and comprise 20 to 50 percent of the overstory, depending on time since disturbance. In the absence of disturbance, canopy cover eventually increases and shades out the birch and aspen. White spruce dominates northern aspects and higher elevations, whereas ponderosa pine dominates southern aspects and lower elevations; pockets of quaking aspen, paper birch, and shrubs occur throughout these areas.

Northern Rocky Mountain Ponderosa Pine Woodland and Savanna (10530)

Geographic area: central Idaho, Montana, northeastern Washington
Elevation: Low to mid
Provinces: M242, M332, 342
Notes: Potential Vegetation Type (PVT) is the ponderosa pine type (USDA Forest Service, Northern Region 2004).

This BpS represents the ponderosa pine series from Pfister and others (1977) and Douglas-fir-ponderosa pine from Williams and others (1995) in the Colville National Forest in Region 6. It occurs on hot, dry south and west-facing on gentle-to-moderately steep slopes adjacent to grasslands and shrublands at its lower elevation limit. Ponderosa pine dominates the overstory, small amounts of Douglas-fir and Rocky Mountain juniper may be present, and shrubs are sparse; grasses include Idaho fescue and rough fescue (table 2.4).

Stand development begins with a mixture of herbaceous plants and/or ponderosa pine seedlings and saplings less than five inches dbh. Without disturbance, stand density increases, a closed canopy develops, density dependent mortality begins, and susceptibility to insects and disease increases. During this time, Douglas-fir may be occasionally present in small amounts. In areas that have experienced recent disturbance or that are too dry to maintain dense stands of trees, the canopy is open and there is greater herbaceous cover. In cases where disturbances maintain the open canopy, the forest develops into an open, park-like ponderosa pine stand with a minor component of Douglas-fir. Seedling regeneration is minimal, with less than 10 percent cover and an understory dominated by grasses. However, in the absence of disturbance, the later stages can be characterized as high density, multi-storied ponderosa pine stands with Douglas-fir regeneration in some sites. A range of tree sizes, from pole-sized to large-diameter trees, are present and susceptibility to insects, disease, and fire hazard is extremely high.

Northern Rocky Mountain Mesic Montane Mixed Conifer Forest (10471)

Geographic area: northern Idaho, northwestern Montana, northeastern Washington
Elevation: Below 5000 ft
Provinces: M332, M333
Notes: Potential Vegetation Types (PVT) include western redcedar moist type 2; habitat types include THPL/CLUN and THPL/ASCA (USDA Forest Service, Northern Region 2004).

Douglas-fir and grand fir usually dominate sites in this BpS, with several other species occurring such as western larch, western white pine, western redcedar, ponderosa pine (warmer, drier sites), Engelmann spruce (cooler sites), and subalpine fir (cooler sites) (table 2.4).

Early stages of stand development are dominated by shrubs such as ceanothus and Scouler's willow and western larch seedlings and saplings; western white pine saplings and seedlings will also be present. As the stand develops, pole-sized western white pine, western larch, grand fir, and Douglas-fir will overtop the shrub layer and begin to dominate. As canopy cover increases and the stand becomes very dense, western redcedar and western hemlock will be present in the understory. Usually, the stand will transition to a closed-canopy stage with pole-sized thickets consisting mainly of western redcedar and grand fir, as well as other species such as western larch. Occasionally, localized disturbances such as mixed severity fires and blow-downs will create a more open, mid-developmental stage dominated by the same species mentioned above. This rare stage can remain open as the stand ages if small disturbances (including diseases) continue to occur, and will include the same species. The more common late developmental stage is one composed of densely stocked groves of western redcedar with a sparse understory due to heavy shading.

Northern Rocky Mountain Foothill Conifer Wooded Steppe (11650)

Geographic area: eastern Idaho, northern Montana, central Oregon, Wyoming, northeastern Washington (Okanogan), eastern Cascades
Elevation: 1600-5300 ft
Provinces: M261, M332, 342

This BpS is found on all slopes and aspects above grasslands and shrublands and below mesic coniferous forests. These areas receive more winter and spring rains than the drier woodlands and savannas in the central Rocky Mountains. Douglas-fir usually dominates but ponderosa pine and limber pine can also occur as incidentals. The understory consists of bunchgrasses (Idaho fescue) and shrubs such as mountain big sagebrush and common juniper (table 2.4).

Early stages of stand development are dominated by Douglas-fir and sometimes limber pine seedlings and saplings in the upper story, with Idaho fescue and mountain fescue in the understory. As the stand develops and canopy closes, limber pine and ponderosa pine may be present along with Douglas-fir; sagebrush has diminished. However, mixed severity fires will create more open conditions and Idaho fescue and sagebrush will remain in the understory. These open conditions with large Douglas-fir, along with some limber and ponderosa pine, are maintained into later stand development by surface fires.

Utah

There are four vegetation descriptions located in Utah. Many of them fall also in southern Idaho within the Great Basin. Figure 2.5 shows the distribution of the vegetation types.

Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland (10610)
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland - Low Elevation (10611)

Geographic area: California, Idaho, Montana, eastern Oregon, Utah, and Wyoming (also in other states that are outside of the study area, such as Arizona, New Mexico, and Colorado)
Elevation: 6000-9000 ft
Provinces: M261, M331, M332, M341, 313, 331, 341, 342

This BpS is considered a fire-adapted community, where in the absence of disturbance, conifers will replace quaking aspen. These include white fir, subalpine fir, and Douglas-fir, and limber pine in BpS 10610 and ponderosa pine, lodgepole pine, and Douglas-fir in BpS 10611 (table 2.5).

Quaking aspen suckers, along with grasses and forbs, dominate the early stage of stand development and after around 10 years (in the absence of disturbance), may reach heights over 6 ft. During this stage, conifers may invade and after 30 years continue to be present in the understory in a closed-canopy forest dominated by aspen. In the event of a fire, this area may transition into an open-canopy forest dominated by quaking aspen, with a conifer understory. In the absence of fire, conifers can dominate within 100 to 150 years, although large-diameter quaking aspens may still be present.

Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (10510)

Geographic area: southern Idaho, Utah, and western Wyoming
Elevation: 4000-8700 ft
Provinces: M331, M341, 341, 342

In this BpS, white fir and Douglas-fir are the most common conifer species; ponderosa pine occurs less frequently. Shrubs include bearberry (kinnikinnick), snowberry, and creeping barberry (table 2.5). At lower elevations this BpS is found above sagebrush ecosystems and adjacent to ponderosa pine woodlands. At higher elevations it is adjacent to spruce-fir forests.

Lodgepole and ponderosa pines seedlings, forbs, shrubs, and grasses such as pinegrass and elk sedge dominate the early developmental stage. If a fire occurs at this stage, it resets vegetative development. In the absence of fire, this stage will succeed to a closed, mid-developmental stage within about 35 years, where canopy cover exceeds 35 percent and Douglas-fir, white fir, and limber pine saplings, poles, and trees dominate the stand. This stage can persist for several decades and future trajectory depends on disturbances. If the stand remains open (<35 percent), pole and sapling Douglas-fir and ponderosa pine will be dominant, with grass and scattered shrubs in the understory.

In the absence of disturbances, the closed, mid-developmental stage succeeds to a closed, late-developmental stage, with canopy cover >35 percent, consisting of white fir, limber pine, ponderosa pine, and Douglas-fir. If a mixed severity fire or insect/disease outbreak occurs, the stand transitions into an open, mid-developmental stage dominated by ponderosa pine and Douglas-fir, with poles, saplings, grass, and scattered shrubs throughout. Late developmental open stages, with large trees and grass and scattered shrubs in the understory, are dominated by Douglas-fir and the occasional ponderosa pine.

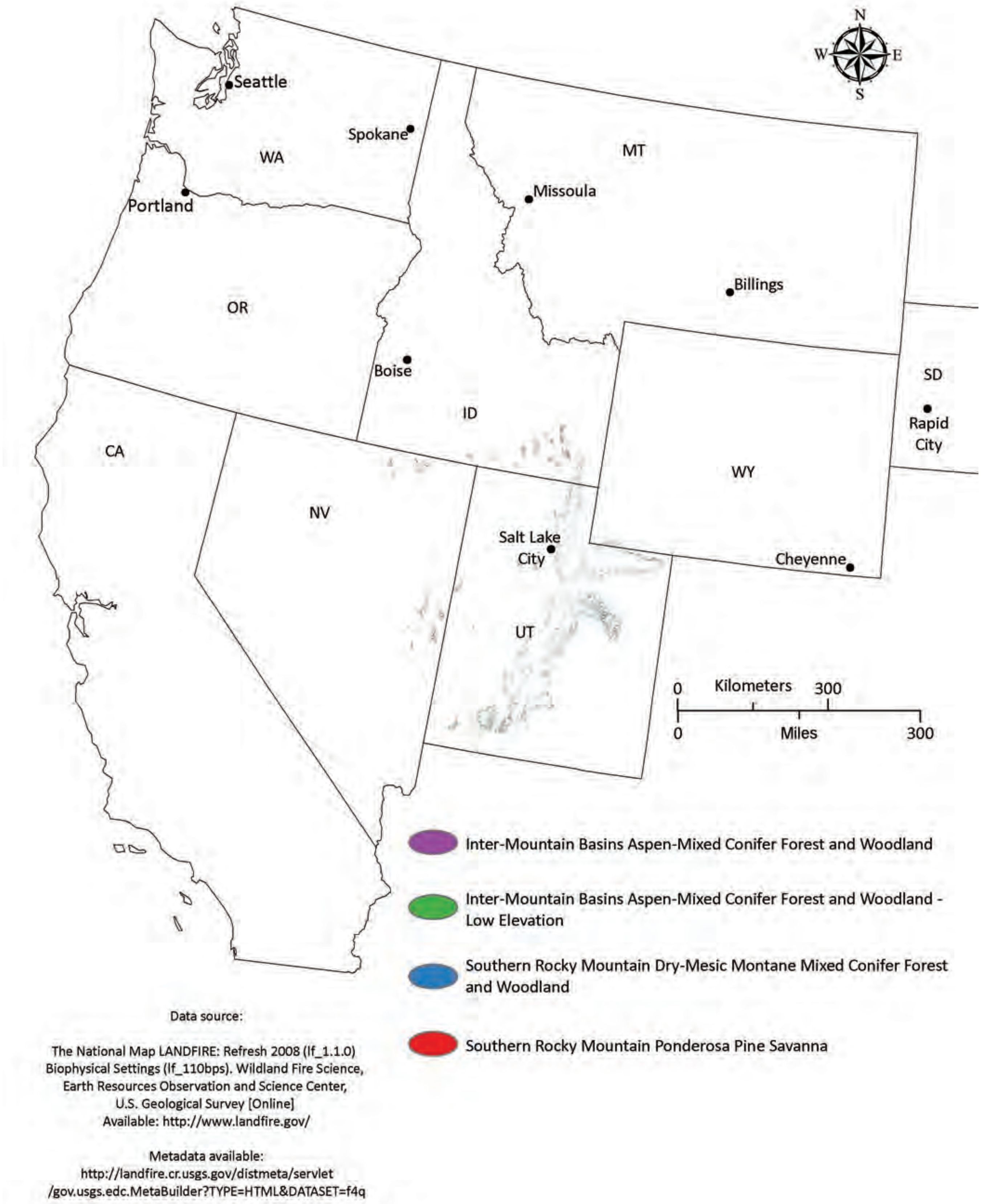

Figure 2.5. Distribution of the biophysical settings (BpS) for Utah.

Table 2.5. Biophysical setting models from the LANDFIRE project (2008) for Utah.

	Utah				
Biophysical setting	**Dominant species[1]**	**Early seral species[1]**	**Late seral species[1] Open stands**	**Late seral species[1] Closed stands**	**Shrub species**
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	quaking aspen, white fir, subalpine fir, limber pine	quaking aspen	quaking aspen, white fir, subalpine fir, limber pine	subalpine fir, white fir, quaking aspen, limber pine	mountain snowberry, currant, serviceberry, chokecherry, Woods' rose, common snowberry, creeping barberry
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland-Low Elevation	quaking aspen, ponderosa pine, lodgepole pine, Douglas-fir	quaking aspen	quaking aspen, white fir, Douglas-fir	ponderosa pine, lodgepole pine, Douglas-fir, quaking aspen	serviceberry, chokecherry, common snowberry, bigtooth maple, spiraea, Woods' rose, creeping snowberry, creeping barberry
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	white fir, limber pine, Douglas-fir, lodgepole pine, ponderosa pine	Douglas-fir, ponderosa pine	ponderosa pine, Douglas-fir, limber pine, white fir	white fir, limber pine, ponderosa pine, Douglas-fir	kinnikinnick, snowberry, creeping barberry, ceanothus species
Southern Rocky Mountain Ponderosa Pine Savanna	ponderosa pine	ponderosa pine	ponderosa pine	ponderosa pine, white fir, Douglas-fir	Shrubs are uncommon (not listed in the BpS model description)

[1]Tree species are in order of dominance.

Southern Rocky Mountain Ponderosa Pine Savanna (11170)

Geographic area: Utah
Elevation: 5500-8900 ft
Provinces: M331, M341, 331, 341

This BpS is found in the southern and eastern Uinta Mountains of northern Utah and on the plateaus and mountains of central and southern Utah. Areas within this BpS are characterized by open park-like stands of ponderosa pine with a grass understory; understory trees and shrubs are uncommon (table 2.5). Grasses include Arizona fescue, bluebunch wheatgrass, and big bluestem.

Early developmental stages are dominated by grasses and scattered thickets of ponderosa pine regeneration, with shrubs present in moist areas. As ponderosa pine reaches sapling to pole-sized, stand trajectory from this point depends on disturbances. In the absence of fire, the trees grow from sapling to sawtimber size (2 to 14 inches dbh), canopy cover can exceed 30 percent, and understory plant cover diminishes. This closed, mid-development forest succeeds to a late-development, closed forest, which has trees >14 inches dbh, severely suppressed understory trees, and a poorly developed understory. If the closed, mid-development forest experiences fire, it usually results in either a stand replacement fire, which can change the area to an early development stand, or a mixed severity fire, which converts the stand to an open, mid-development stand with trees ranging from 2 to 14 inches dbh and canopy cover <30 percent. However, if low intensity and mixed severity fires maintain the stand, it remains open. Once the trees reach >14 inches dbh the stand is considered to be late-successional. Again, disturbance dictates if the stand is open or closed. Surface fires maintain an open, savanna-like stand with a grass- and shrub-dominated understory. In the absence of fire, the stand transitions to a closed, late-successional forest as described above.

Conclusion

The purpose of this chapter is to described the wide range of forest compositions and developmental stages of the dry mixed conifer forests within the synthesis area to help guide fuel treatments. Knowing what species composition and forest structures to expect during different stages of stand development and how these stages are affected by disturbances can help with making management decisions. For example, identifying which BpS are present within a management area and their current developmental stage can provide a basis for evaluating fuel conditions, whether fuel treatments are necessary, and what methods to use. In addition, because there is variability among these BpS concerning site conditions, particularly with regards to moisture, productivity can vary. Therefore, information concerning expected developmental stages following fuel treatments and how often treatments need to be applied can be useful.

Further Reading

Many of the references below were used in the LANDFIRE BpS descriptions. The descriptions can be found at: http://www.landfire.gov/national_veg_models_op2.php.

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Chapter 3

The Role of Disturbance and Climate in Sustaining Dry Mixed Conifer Forests

Introduction

Dry mixed conifer forests are disturbance-driven, meaning that combinations of disturbance collectively drive forest development, structure, and composition (Attiwill 1994) (fig. 3.1). Natural disturbances are integral to the ecological processes operating in these forests, altering both stand structure and species composition. Over time, such disturbances create and maintain a diverse distribution of successional stages and vegetation types across the landscape. Within the synthesis area, several tree species have characteristics that lend resilience to forests where they occur. The more resilient trees, such as western larch and ponderosa pine, require moderate to high light intensities and are comparatively drought-tolerant. As trees of these species mature, they also exhibit increased resistance to fire, such that their largely intact post-fire canopy tends to help the species maintain site occupancy. Trees of other species may not survive a fire, but their presence may be maintained or restored via sprouting or regeneration from seed post-fire. Other disturbances, such as insects and diseases, also affect forest structure and, because they are often host-specific, the result is variation in species composition.

Resilience

Resilience is the capacity of a plant community or ecosystem to maintain or regain normal function and development following a disturbance (Helms 1998).

In this chapter, we discuss the disturbances that have been driving vegetation development in these landscapes, starting with a detailed inventory of disturbance agents and how they manifest themselves. This is followed by a regional tour of fire regimes, focusing on fire return intervals and size, along with the temporal and spatial variance in post-fire outcomes in each subregion. We provide a brief crash course on what is known today about global-scale climate cycles and their role in the remarkable variety of weather observed in the dry mixed conifer region. Climate and weather have important implications for fire periodicity, spatial and temporal grain, and the complex and constantly shifting assemblages of species and structures present on the landscape today. As changing climate trends are superimposed on all current climate cycles, succession processes and other drivers will influence and change the environment in which forests grow and develop. Disturbances are part and parcel of that trend driver, and fire is perhaps the dominant one—and likely to accelerate the shifts, for example, in the ranges of individual species. For silviculturists, fuels specialists, and fire managers charged with steering this key disturbance agent by manipulating vegetation, an understanding of how all these pieces fit together is crucial. We conclude the chapter with a discussion of how the variation in fuels, topography and weather combine and overlap to create mixed fire regimes, and provide a primer on vegetation autecology and fire tolerance to enhance understanding of vegetation impacts from fire, and the process of post-fire recovery.

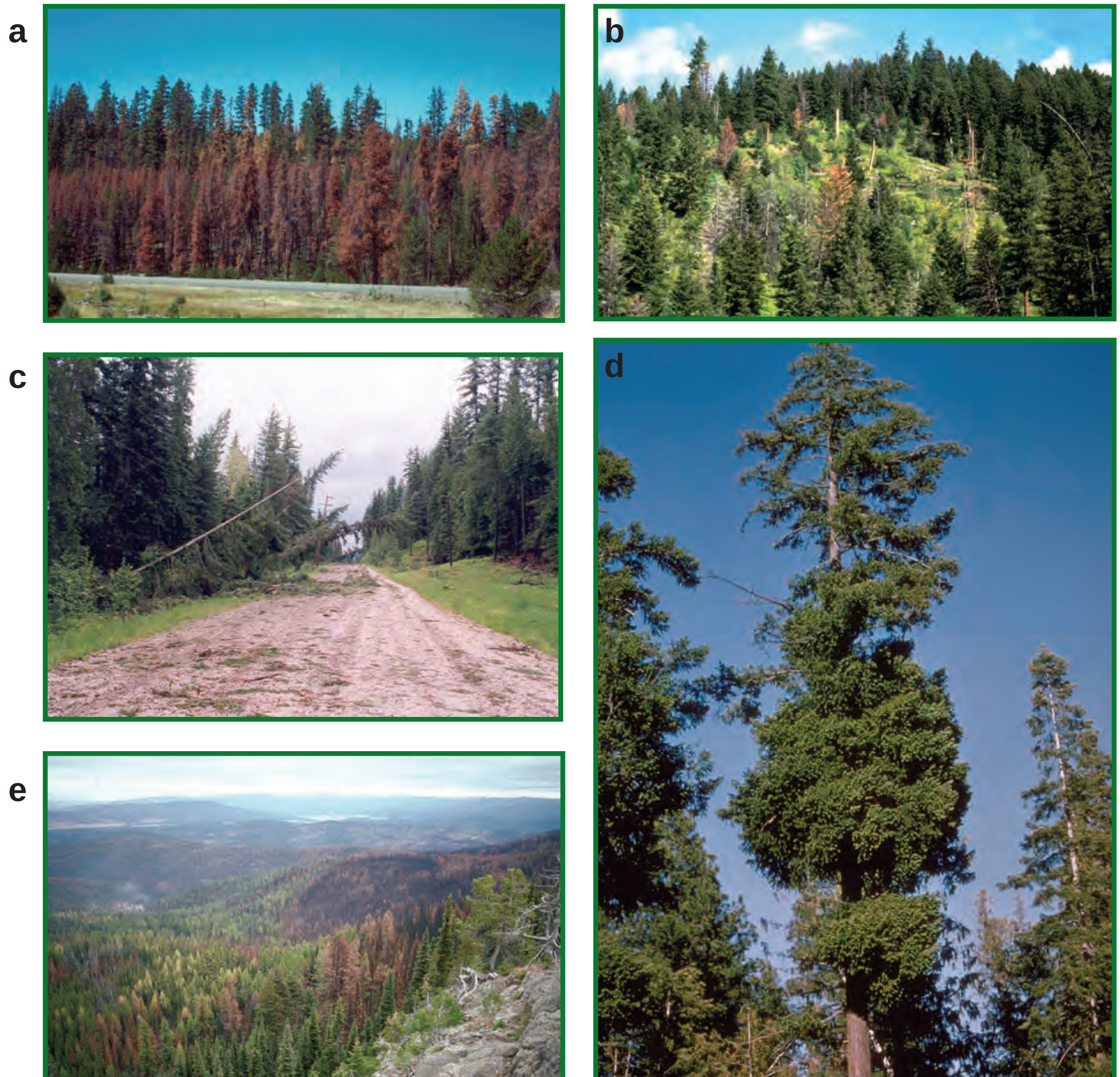

Figure 3.1. The dry mixed conifer forests are disturbance driven. Where insects (a), disease (root disease (b), weather (ice, wind, snow) (c), mistletoe (d), and fire (e) all play a role in creating a variety of forest compositions and structures. Photos a, d, and e by David Powell, USDA Forest Service, b by Ralph Williams, USDA Forest Service, and c by Robert Denner, USDA Forest Service. Photos a, b, d, and e from Bugwood.org.

Disturbance

Pickett and White (1985) defined a disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Moreover, disturbances interact with each other to create conditions that promote and/or alter subsequent disturbances (Hessburg and Agee 2003).

The epidemic-scale mountain pine beetle infestations (as of 2012) in some dry mixed conifer forests of the western United States are altering species composition by targeting host species (lodgepole pine and/or ponderosa pine) and allowing non-host tree species to expand their site occupancy (fig. 3.2). In some cases, when established trees are not present, the outcome is an open stand containing shrubs or other vegetation. A period that is particularly important in terms of fire hazard occurs when a tree has been attacked but the needles are green or in the red needle stage (prior to needle drop). Recent literature has noted that decreased moisture and change in foliar chemistry increase flammability (Hicke and others 2012; Jolly and others 2012). After infestations, substantial increases in surface fuel loads occur as infested trees respond by shedding needles and branches in the short-term, and by transitioning to snags and down wood over the long-term. More importantly, beetle infestations create open forests, favoring an increase in wind speed, decreased air relative humidity, and higher air temperature—all factors that influence fire behavior. This interaction of species composition change along with increased surface fuel loadings and weather variables will likely alter the potential fire behavior and fire effects in these forests compared to those of uninfested forests (Jenkins and others 2008; Klutsch and others 2009). However, the combination of beetle mortality and increased likelihood of fire creates opportunities for a variety of species to expand their occupancy of the site and

Figure 3.2. Mountain pine beetle infestation with Mount Jefferson in the background. Taken from the Warm Springs Indian Reservation by Andris Eglitis, Entomologists, Deschutes National Forest.

may generate new habitat niches (Lehmkuhl and others 1994). Synergistic combinations are possible for the many kinds of disturbance common in dry mixed conifer forests, including insects, diseases, wind, and snow/ice damage. Understanding the interactions among natural disturbances and how the resulting forests create conditions that promote different fire behaviors, intensities, and burn severities are important for planning and implementing fuel treatments.

Weather

Weather can be a formidable disturbance in dry mixed conifer forests. Snow, ice, and wind can create canopy openings sometimes tens of acres in size (Boldt and Van Deusen 1974; Shepperd and Battaglia 2002). Moreover, these disturbances are episodic, isolated, and indiscriminant in terms of location and spatial extent. Wind is a common disturbance that can create a variety of patch sizes by creating gaps and shattering individual trees. Intense isolated thunderstorms can cause considerable damage and increase surface fuel amounts (fig. 3.3); large windstorms can affect hundreds or thousands of acres. Although wind is recognized as a major disturbance, much of the focus on this disturbance has been centered on hurricanes, a form of disturbance extremely rare if nonexistent in our synthesis area, and little attention has been devoted to wind's effect on fuel dynamics. However, there is a long history of wind events in the Pacific Northwest with an estimate of 48 notable wind storms that occurred between 1880 and 2007 (Read 2008), resulting in a mean return interval of 2.6 years (standard deviation of 4.5) and a range from less than 1 to 26 years. Winds associated with thunderstorms account for half of all severe weather reports in the lower 48 states and are more common than damage caused by tornadoes (http://www.nssl.noaa.gov/primer/wind/). Damaging winds are those that exceed 50 to 60 mph, a point at which wind can uproot trees and break boles. In dry mixed conifer forests, ponderosa pine, western larch, and Douglas-fir are more resistant to wind damage than other species (Minore 1979); however, even trees of these species can be damaged in major wind events. Silvicultural prescriptions designed to reduce

Figure 3.3. Windstorm damage at Priest River Experimental Forests. Photo by Robert Denner, USDA Forest Service, Rocky Mountain Research Station.

crown fire potential by reducing canopy density can make the remaining trees more susceptible to wind damage, and lead to an increase in surface fuels in the short-term. Over the long-term, the lower stand densities created by thinning promotes increases mechanical stability and wind resistance (Wonn and O'Hara 2001). Thoughtful silvicultural prescriptions acknowledge information on tree susceptibility to reduce wind damage and increase wind firmness. These factors include tree age (young trees fare better than old trees), topographic influences and wind direction, and species composition. Treatment design and layout can also be incorporated. For example, Smith and others (1997) suggest that arranging a sequence of strips or strip-shelterwood blocks oriented from leeward to windward can create a streamlined pattern that increases stand resistance to downbursts.

Ice and snow can cause significant damage in dry mixed conifer forests. Russ Graham (personal communication) offers anecdotal evidence of clear, windless winter days during which heavy snow dropped onto the large branches of grand fir as it melted, causing these trees to break and topple like dominoes. As with wind, historical records are limited for assessing the frequency and severity of snow and ice storms. Ice accumulation varies with topography, elevation, aspect, and the areal extent of susceptibility (Irland 2000). In mixed conifer forests, deciduous conifers (for example, western larch) and fine-needled pines (for example, western white pine, sugar pine) tend to shed snow and ice. Others, with fuller crowns (for example, grand fir, Douglas-fir) tend to be more susceptible to ice and snow damage. Damage ranges from minor branch breakage, to major branch and crown loss and breakage of trunks within or below the crown (Jain and Graham 2005) (fig. 3.4), resulting in canopy gaps, decreased forest densities, and altered species composition (Jain and Graham 2005).

Figure 3.4. 1996 snow damage in northern Idaho. Photo by David Koob, USDA Forest Service.

Insects and Disease

Within dry mixed conifer forests, fire exclusion allowed dense stand conditions to develop, thereby increasing the likelihood of insect and disease epidemics. These can dramatically alter forest composition and structure (Harvey and others 2000) (table 3.1).

Table 3.1. Common diseases and insect pests for conifers throughout the synthesis area (compiled from Hagle, Gibson & Tunnock, 2003). DF- Douglas-fir; GF - grand fir; ES - Engelmann spruce; JP - Jeffrey pine; LP - lodgepole pine; PP - ponderosa pine; SRF - Shasta red fir; SPF - subapline fir; sugar pine – SP; WH - western hemlock; WL - western larch; WRC - western redcedar; WWP - western white pine; WF - white fir. We did not include sudden oak death, which can infect oak species in Oregon and northern California.

	Species	DF [1]	GF	ES	JP	LP	PP	SRF	SPF	SP	WH	WL	WRC	WWP	WF
Stem decay	Blue stain	X	X		X	X	X	X							X
	Cedar brown pocket rot												X		
	Indian paint fungus		X					X	X		X				X
	Pini rot	X		X	X	X	X			X	X	X	X	X	
	Pouch fungus	X	X		X			X	X	X	X		X	X	X
	Red belt fungus	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Schwinitzii butt rot	X		X								X		X	
Cankers	Atropellis canker					X									
	Fir canker	X	X					X	X						X
	Spruce canker	X		X											
Root diseases	Annosus	X	X	X					X		X		X	X	
	Armillaria	X	X					X	X		X	X	X	X	X
	Blackstain	X					X								
	Laminated root rot	X											X		
	Tomentosus root disease			X		X									
branch and terminal	Camandra & Stalactiform					X	X								
	Dwarf mistletoe	X			X	X	X	X				X			X
	Needle cast	X				X	X		X	X		X		X	X
	Swiss needle cast	X													
	White pine blister rust					X	X			X				X	
	Brown felt blight			X					X						
	Larch needle blight											X			
	Spruce broom rust			X											
	Western gall rust					X	X								
	Larch Casebearer											X			
	Larch sawfly											X			
	Western spruce budworm	X	X												
	Lodgepole terminal weevil					X									
Beetles	Cedar bark beetles												X		
	Douglas-fir beetle	X													
	Jeffrey pine beetle				X										
	Mountain pine beetle					X	X			X					
	Pine engraver beetle				X	X	X								
	Western pine beetle						X								
Wood borers	Fir engraver		X					X							X
	Metallic wood borers	X	X	X					X		X	X	X		X
	Roundheaded borers	X	X	X					X		X	X	X		X

Hessburg and others (1994) noted that bark beetles, defoliators, and diseases exert considerable influence on the composition and structure of northwestern forests. Bark beetles active in northwestern forests include western and mountain pine beetle, pine and fir engraver beetles, Douglas-fir beetle, and spruce beetle. Defoliators include western spruce budworm and Douglas-fir tussock moth. Diseases include laminated root rot, *Armillaria*, *Annosus*, Indian paint fungus, blister rust, and brown cubical butt rot. Dwarf mistletoe, though actually a parasitic plant, not a disease per se, is the most common and easily identified damage agent influencing conifer species and may increase with climate change (Woods and others 2010). Many of these agents can be found in dry mixed conifer forests, and the majority of the impacts of insect and pathogen agents have occurred in these forests.

Western pine beetle was a primary insect associated with historical fire regimes. Large, old ponderosa pine trees, preferred by the beetle, were vigorously attacked when stressed by drought and had little capacity to resist (Hessburg and others 1994). For example, the drought of 1920s and 1930s killed many trees (Miller and Keen 1960). In years not characterized by drought, the western pine beetle is endemic and typically kills trees that have been struck by lightning, that are infected by root disease, or that are too old to successfully resist attack. However, some management activities, such as reintroducing fire after decades of fire suppression absence can make normally resilient trees susceptible to attack (see Chapter 10) (Hood 2010; Wu and others 1996) (fig. 3.5).

Figure 3.5. Western pine beetle attack in ponderosa pine, this photograph was taken by Andris Eglitis from the Deschutes National Forest.

Mountain pine beetle readily attacks lodgepole pine and ponderosa pine within the Douglas-fir and grand fir PNVGs (fig. 3.6). Leiberg (1899) and Langille (1903) recorded the first insect outbreak in the northern Rocky Mountains more than a century ago. Although these turn-of-the-century outbreaks were severe, evidence suggests that their extent and duration were less than contemporary infestations. Before the advent of fire suppression, fires created a heterogeneous pattern of forest developmental stages, and stands at a vulnerable stage of development tended to be spatially isolated, limiting the extent of infestations. Today, these same forested landscapes are characterized by large expanses of single developmental stages, and this facilitates larger and more severe infestations (Hessburg and others 1994). Historically, pine, Douglas-fir and fir engraver beetles tended to kill trees scorched by low-intensity surface fires. Where stand densities are high, forests are stressed by drought, or trees are infested by disease, mistletoe, or root rot, engraver beetles would attack susceptible trees in old growth refugia. Evidence indicates that there were periodic outbreaks of western spruce budworm and Douglas-fir tussock moth in the 1700s and 1800s (Hessburg and others 1994; Wickman 1992). These outbreaks were limited in extent and duration because the host species (Douglas-fir, grand fir, and white fir stands) were discontinuous and dispersed. Also, the host species tended to occur in mixed stands containing ponderosa pine, western larch, and other early-seral or non-host species, reducing both the impact of the defoliation and its rate of spread.

Figure 3.6. Ponderosa pine killed by mountain pine beetle; couple years after infestation. Photo by David Powell, USDA Forest Service, and obtained from Bugwood.org

Beetles and fuels

Over the past several decades, bark beetle outbreaks have affected millions of acres of western coniferous forests (Man 2010; Raffa and others 2008). These outbreaks have altered the fuel complex of dry mixed conifer forests. Recent reviews have addressed how the fuel complex is affected by such outbreaks in lodgepole pine and Engelmann spruce-subalpine fir forests (Hicke and others 2012; Jenkins and others 2012), and these findings hint at how fuel complexes will change in dry mixed conifer forests that may be relevant. However, we would expect a different extent and magnitude of change in dry mixed conifer fuel complexes owing to the presence of non-susceptible species, which could mitigate stand-level impacts and influence the extent of the outbreak.

Forests impacted by beetle outbreaks transition through three stages. In the first, "red," stage, needles on beetle-killed trees fade to a reddish color. Within 1 to 5 years, these needles separate and fall from the branches, increasing the litter fuel loading, and leaving behind a "gray" stage of standing, gray-colored snags that continue to shed twigs and branches over many years, adding to fine fuels on the forest floor. During both of these stages, increased light resulting from canopy opening facilitates establishment by shrubs, graminoids, forbs, and seedlings, ultimately increasing the potential for future problems with ladder fuels. At the same time, advanced regeneration and tree species not vulnerable to beetle attack respond with increased growth rates. Eventually, the snags decay and fall at rates that vary based on site characteristics and species, generating increased loadings of coarse, surface fuels. This "post-epidemic" phase can last up to several decades.

Strategies for managing fuels in bark beetle infested forests depend on the intensity and distribution of mortality. In some cases, managers have capitalized on the beetle induced mortality pockets and the stand heterogeneity it created. Managers have used resulting pockets of mortality as focal points in which to create holes, gaps, and meadows within the stand as wildlife habitat enhancement; to increase stand and landscape structural and compositional heterogeneity; and to alter potential wildfire behavior. Jenkins and others (2012) raise several important considerations from a fire suppression perspective. Removal of dead trees has been proposed to facilitate firefighter safety and effectiveness, for example, to prevent injury by falling snags during a fire, to provide more areas for safe zones in which fire shelters can be deployed, and to facilitate future fireline construction. Leaving nature to take its course in a stand containing an abundance of beetle-killed trees and the increasing surface fuel loadings they will generate effectively increases the area of fuelbeds that will be receptive to fire brands. Such increased spotting potential could greatly impact fire suppression effectiveness and compromise firefighter safety.

Figure 3.7. Root disease in dry mixed conifer forests. Root disease maintains high surface fuel in the form of woody debris and tall shrubs for decades. These pockets can be several acres in size and occur throughout the dry mixed conifer forests. Photo by John Schwandt, USDA Forest Service.

The root diseases that occur in dry mixed conifer forests are laminated root rot, *Armillaria* root disease, and *Annosum* root rot, and they typically occur in spatially aggregated clusters known as root rot centers (table 3.1). Douglas-fir and grand fir are particularly susceptible to root diseases. Historically, these diseases provided structural diversity and enhanced diversity in opening size, shape, and edge of patches (Hessburg and others 1994; Spies and Franklin 1989). Patches created by these diseases most likely contributed to the mixed fire regime because the patches were more likely to support moderate and high severity fire. These root rot centers generate snags and woody debris that eventually decompose and are incorporated into the soil. However, they can produce a significant amount of woody fuel and perpetuate ladder fuels (Hessburg and others 1994). *Armillaria* root disease is an opportunistic pathogen in that it attacks low-vigor, older, or weakened and injured trees. *Armillaria* also attacks stressed trees affected by drought, lightning, fire, or other root pathogens (fig. 3.1).

Root disease and fuels

Rippy and others (2005) identify critical elements meriting attention when conducting fuel treatments in areas infested by root disease. Thinning may lead to increased damage from some root diseases (e.g., *Armillaria*, laminated and *Annosus* root disease), particularly if root disease is already well-established and residual trees are of susceptible species (e.g., true firs and Douglas-fir), so it is important to select leave trees of disease resistant species, such as western larch, ponderosa pine, sugar pine, and western white pine (table 3.1).

Timing of treatments may also be important, as there is some preliminary, though not entirely conclusive, evidence that thinning in summer or fall leads to less root disease damage than in spring, perhaps because warmer temperatures favor the establishment of other kinds of fungi in newly created stumps, leaving no unfilled niche in which detrimental root disease fungi can become established. Where root disease is evident, it is important to prevent wounding of residual trees, whether through prescribed fire or mechanical injury. Favoring tree species diversity, using locally adapted seed sources, and promoting tree vigor are all practices that reduce vulnerability to root disease. Rippy and others (2005) also suggest more aggressive practices such as removing stumps and push-felling to extract root systems. However, it would be important to evaluate the effects of such practices on soil productivity, and economic feasibility may be difficult to establish without better information on the effect on rates of disease impacts and operational costs.

Dwarf mistletoe can occur in several coniferous species (Hessburg and others 1994; Parker and others 2006) (fig. 3.8). Mistletoe in ponderosa pine creates an abundance of brooms, fine fuels, resinous stems and branches, and occasionally dead trees. During surface fires, these mistletoe-infested trees tend to torch and a fire can kill severely infected trees and small infected patches. In Douglas-fir, mistletoe brooms (clusters of branches) have been observed to interfere with the self-pruning that typically occurs as a result of competition among trees in a stand, leaving flammable ladder fuels between forest floor and canopy. Abundant mistletoe in Douglas-fir most likely contributed to the high fire intensity observed during the Bitterroot fires of 2000. Historically, dwarf mistletoe in western larch was perhaps the most widespread, because western larch can live long periods and survive fires even with mistletoe infection, so the mistletoe also survives.

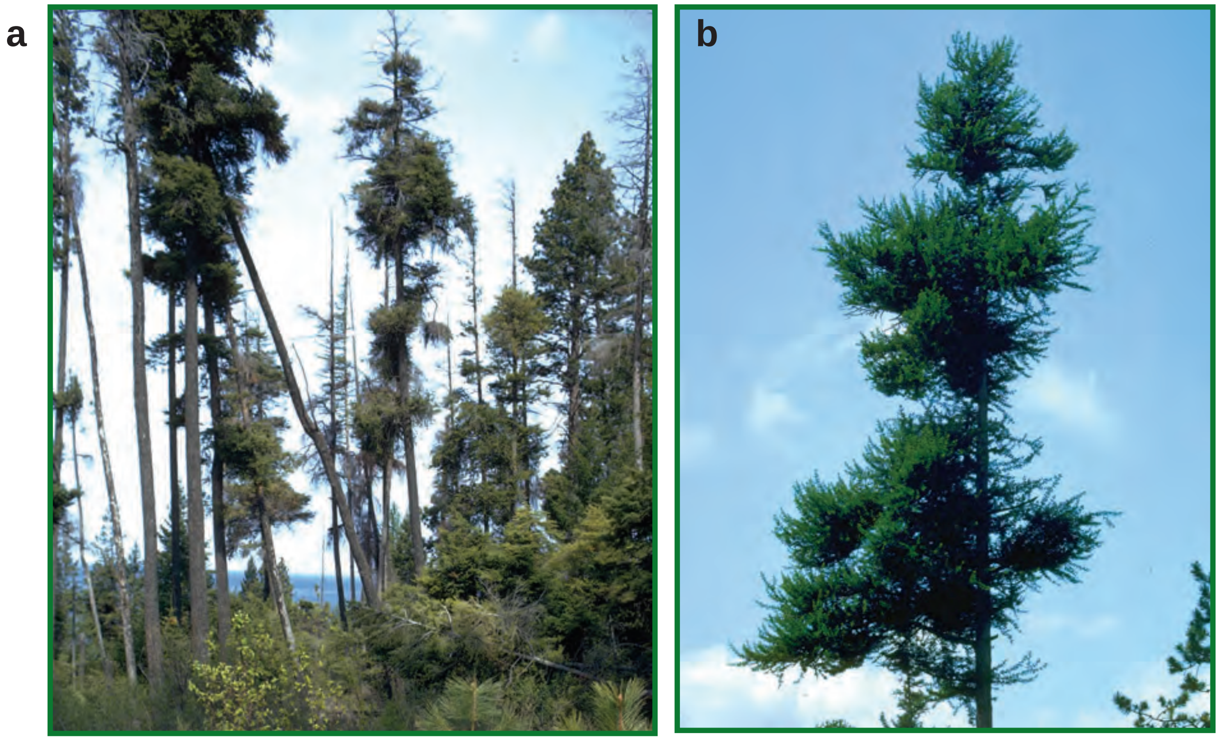

Figure 3.8. Dwarf mistletoe on Douglas-fir (a), western larch (b), lodgepole pine (c), and ponderosa pine (d). Photos a and b by Oscar Dooling (USDA Forest Service), photo c by William Jacobi (Colorado State University), and photo d obtained from Bugwood.org.

Mistletoe and fuels

Fire does not necessarily decrease the area affected by mistletoe; however, even predominantly surface and low-intensity fires tend to kill the most infected trees because the extreme branching and "brooms" created by mistletoe infection act as a fuel ladder that conveys fire into the crowns of infected trees. Prescribed fire and mechanical fuel treatments can reduce tree densities and elevate canopy base height to discourage crown fire; but by selecting infected trees for removal, they can also reduce mistletoe seed dispersal, and via reduction in sapling densities, reduce the probability of mistletoe seed dispersal to susceptible saplings and lateral spread among the host tree species (Hessburg and others 1994; Stanton and Hadley 2010).

Perhaps due to our perceived success in fire exclusion, fire has often been noted as the primary disturbance regime responsible for having maintained resilient forests. We suggest that a combination of disturbances other than fire also played key roles in creating the variety of compositions and structures that we see today, and which are responsible for both the fuel diversity that drives mixed-severity fire regimes and that created wildlife habitat. Parker and others (2006) noted that the two- and three-way interactions of storms, forest insects, pathogens, and fire created and maintained forests that were dominated by resistant species to insects, disease, and fire. It is important to recognize the contribution of these diverse disturbance forces when planning fuel treatments.

Fire Regimes

Fire is a fundamental ecological process that modifies forest composition, density, and surface fuel loads. How this modification is achieved depends on many factors, including the type of fire (intensity and severity), the amount and arrangement of fuels (aerial and surface), topography, and site productivity. In addition to these factors, local and broad scale climatic conditions create regional variability in fire frequency, behavior, and effects. In this section, we define and discuss common terms used when discussing fire and highlight some of the variability in fire within the synthesis area.

Fires and other disturbances create mosaics of forest composition and structure within and among stands and across landscapes. These mosaics can occur over a range of scales, from relatively fine scale, with patches smaller than an acre, to broad, landscape scales with patch sizes exceeding hundreds of acres (Perry and others 2011). Wildfires historically burned dry mixed conifer forests at a range of intensities and frequencies giving rise to a wide variety of burn severities, and creating diverse post-fire environments. Thus, contemporary vegetation compositions and structures reflect a variety of successional pathways, and both the vegetation and forest floor tend to be especially diverse.

A generalized description of the role fire plays in a forest is termed a fire regime and is typically articulated in terms of frequency, severity, and intensity of fire (Agee 1993). In this synthesis we will use fire severity as the description of a fire regime because it relates directly to disturbance and subsequent effects on vegetation development after a fire and is more commonly used among resource managers and stakeholders to describe fire's role (Smith 2000; Smith and others 2008). The three kinds of fire regime classes most useful for characterizing fires that occur in dry mixed forests are high severity (typically lethal to most trees), mixed severity fires, and low severity fires (typically non-lethal to most trees) (Hann and others 1997; Schmidt and others 2002).

Fire types

The fire hazard for any particular forest or landscape relates to the potential for the particular fuel conditions to cause specific types of fire behavior and effects. There are three types of fires. A *ground fire* spreads within the organic layers beneath the surface litter and typically smolders with a slow-moving rate of spread. *Surface fires* burn forest floor litter and debris as well as low understory vegetation. Partly because they tend to occur under more extreme weather conditions, *Crown fires* typically have a rapid rate of spread and move through the tops of trees or shrubs. Some practitioners further divide crown fire into more refined classes based on specific aspects of fire behavior. *Passive crown fires* occur when a tree or a group of trees is ignited by the passing front of the fire, but the flames do not actively move from tree crown to tree crown (trees experiencing passive crown fires are sometimes described as torching or candling). In an *active crown fire,* a continuous volume of flame develops in the tree crowns and on the surface as a linked and interdependent unit (NWCG 2011). A subcategory of the active crown fire is the *independent crown fire*, which occurs when the fire advances in the tree crowns, not requiring any energy from the surface fire to sustain combustion or forward progress (sometimes referred to as a running crown fire) (NWCG 2011). A conditional crown fire is when canopy base height is too high, thus this prevents a surface fire to transition to a crown fire. But the canopy bulk density can support the horizontal spread of a crown fire (which is possible but rare).

Low severity fires (non-lethal) have frequent fire return intervals, create very small patch sizes, and have very little edge (Hessburg and Agee 2003) (fig. 3.9). These fires clean the forest floor of vegetation and accumulated woody debris, yet leave the majority of the high forest cover alive. Soil burn severity can range from non-existent to highly severe depending on the amount, condition, and extent of the surface fuels and the heat and residence time of the fire.

High severity fire regimes kill canopy layers across stands or even larger areas (fig. 3.9). In general, these fires kill all or virtually all standing vegetation through either crown fires or high intensity surface fires and are classified as severe, though some trees may exhibit evidence of moderately severe fire (for example, brown needles remain attached to branches, at least temporarily) in some areas. Within forests containing burned and blackened trees, the level of soil burn severity can be highly variable, ranging from light to highly severe depending on the state of the ground-level vegetation, surface fuels, forest floor, and fire weather. These fires tend to occur in high-elevation forests and grow large (hundreds of acres, with few if any unburned patches); however, they are infrequent (Hessburg and Agee 2003).

Mixed severity fire is the most diverse fire regime because it can contain both low severity and high severity fires and everything in between (Arno and others 2000; Hessburg and Agree 2003) (fig. 3.9). Most importantly, the key phrase associated with this fire regime is "inconsistent and highly variable." Smith (2000) discussed the elements that comprise a mixed-severity fire regime.

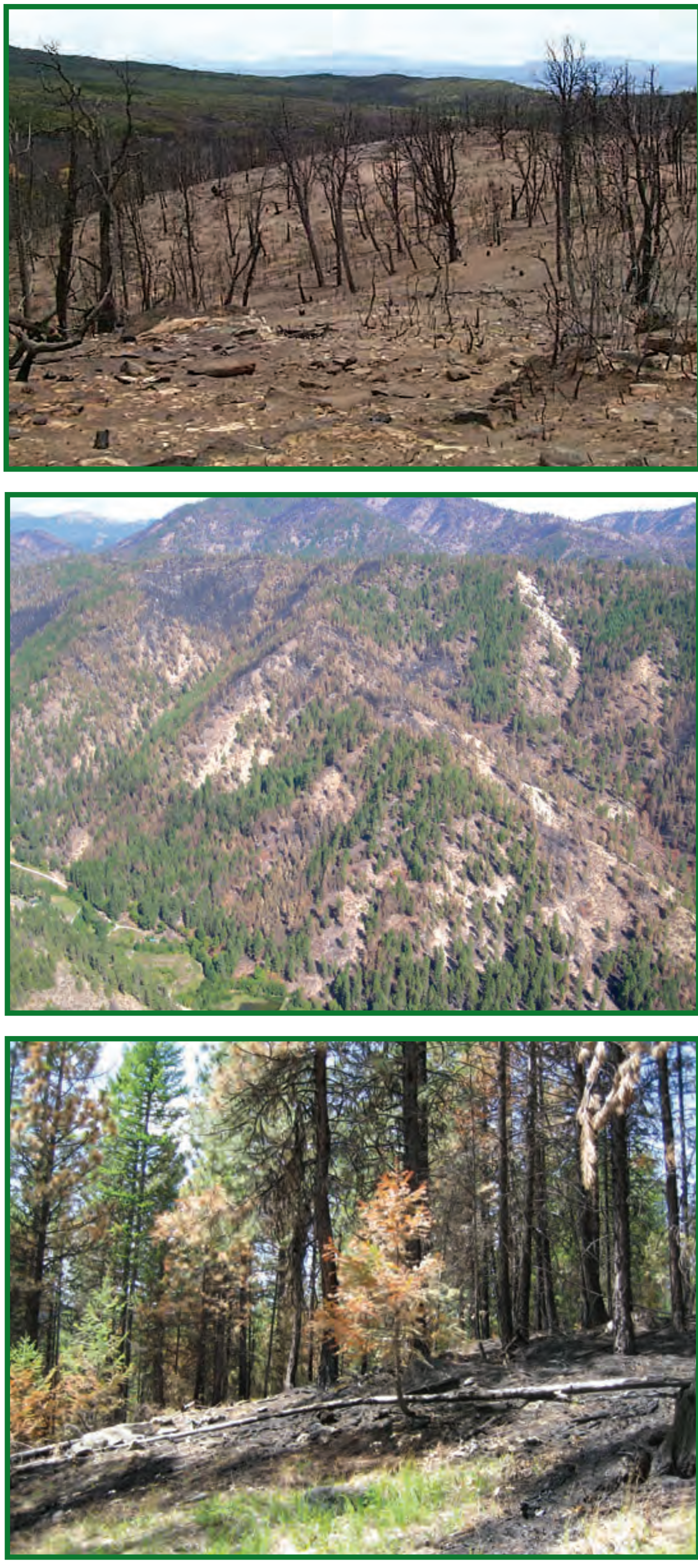

Figure 3.9. Examples of a high, mixed, and low severity fire. The high severity post-fire outcome was taken after the Bitterroot fires of 2000 by Jonathan Sandquist, USDA Forest Service. The mixed severity fire (middle) photo was taken on the Wenatchee National Forest by Paul Hessburg. The low severity post-fire outcome (bottom) photo was taken by Tim Baumgarner, USDA Forest Service.

1. Mixed severity fires contain a diversity of post-fire outcomes concerning soil effects and degree of tree mortality. Surface fires kill many smaller trees, but many larger, fire resistant species have sufficient size and thick bark to survive.
2. Mixed severity fire regimes also vary over space, resulting in a fine-grained pattern of forest structure and composition. This fine-grained pattern is most likely the result of fluctuations in weather during fires, daily changes in burning conditions (Perry and others 2011; Halofsky and others 2011), and variation in topography, surface fuels and stand structure, and composition. This type of fire regime tends to be favored in highly dissected terrain.
3. The type of fire and its severity varies over time and is often referred to as a variable fire regime. These fires may burn for days to weeks or months; but within that period can be highly variable.

Leiberg (1897), while conducting vegetation inventories in the northern Rocky Mountains, referred to fires burning for months—smoldering or torching depending on the conditions. Another example is the 1910 fire in the northern Rocky Mountains. The fires started in early June and burned most of the summer prior to the August blow up (Pyne 2001). Thus, this fire regime can be described as a spatially heterogeneous combination of fire types that kills small- to medium-sized groups of trees in some areas, while burning surface fuels and leaving behind live trees in other areas. The abundance of edges and clumps in forest structure, composition, and successional stages creates a mix of habitats that are often suitable for a variety of early, mid-, and late-successional plant species and wildlife specialists. Low and mixed severity fires are the most common kind of fire found in dry mixed conifer forests; however, even within the mixed severity fire regime, as the term implies, there may be areas within the dry mixed conifer that have consistently experienced low severity fire regimes. However, because of the vegetative mosaic, these areas are often smaller in extent or vary across the landscape.

A historical fire regime refers to a combination of fire frequency and severity under which plant communities evolved and were maintained (Schmidt and others 2002). Five fire regimes are currently recognized (Barrett and others 2010). These five groups include: I – frequent (0 to 35 years), low and mixed severity; II – frequent (0 to 35 years), replacement severity; III – 35 to 200 years, low and mixed severity; IV– 35 to 200 years, replacement severity; and V – 200+ years, replacement severity. The majority of the dry mixed conifer forests in our synthesis area is classified as fire regime group I (frequent 0 to 35 years, low and mixed severity) and group III (35 to 200 years, low and mixed severity).

Regional Variability in Fire Regimes

Many fire history studies and historical narratives on fire regimes completed throughout our synthesis area provide some evidence of the variability in fire history across the region (table 3.2). This variation in fire occurrence is a critical element sometimes overlooked, but it has important implications for creating diversity in forest structure and composition (Agee 2003). In general, fine dead fuels can accumulate quickly in dry mixed conifer forests because of their productivity; they are also more continuous and, therefore, create intermediate-sized patches (Hessburg and Agee 2003). Fire intensities in the drier sites with grass or kinnikinnick understories burn less severely and occur more often than the more productive sites that favor snowberry, ninebark, or huckleberry (Agee 1994). They also burned in a mosaic of small- to medium-sized patches (in tens of acres) with high amounts of edge between patches (Hessburg and Agee 2003). For example, this created "clumped distributions" of ponderosa pine, sugar pine, and white fir near Crater Lake, Oregon (Agee 1994). We suspect that clumpy species composition across the landscape is an important element of these forests. The clumps and openings provided a variety of wildlife habitats and opportunities for different vegetation to establish, grow, and develop. They also disrupted the abundance and the continuity of disease and insect prone species, decreasing the extent and severity of other disturbances.

Table 3.2. Fire history and fire regime literature on dry mixed conifer forests within the synthesis area.

Author	Date	Region	Subject
		North and Central Rocky Mountains	
Arno	1976	Bitteroot Mtn.	Historical narrative of the role of fire
Arno	1980	Northern Rocky Mtn.	Fire history dry and moist mixed conifer forests
Arno and others	1995	Bitteroot Mtn.	Historical Range of Variability
Arno and others	2000	Northern Rocky Mtn.	Historical narrative of mixed fire regimes
Brown and others	1994	Selway-Bitterroot Mtn.	Historical fires and current wildfires
Brunell and Whitlock	2003	Clearwater, Idaho	Sediment cores fire, vegetation, and climate history
Brunell and Whitlock	2005	North central Idaho	Sediment cores fire and vegetation
Cissel and others	1999	Blue Mtn.	Management strategy based on fire regimes
Heyerdahl and others	2001	Interior northwest	Spatial controls of historical fire regimes
		Pacific Northwest Interior and Northern California	
Agee	1994	Eastern Cascades	Summary of fire history studies
Agee	2003	Eastern Cascades	Historical range of variability
Agee	1991	Klamath Mtn.	History
Collins and Stephens	2010	Sierra Nevada	Patch mosaic in mixed conifer
Colombaroli and Gavin	2010	Klamath Mtn.	Charcoal in sediment cores
Cwynar	1987	North Cascades	Pollen, plant macrofossils, charcoal in sediment cores
Everett and others	2000	East Cascades, WA.	Fire history of ponderosa pine/Douglas-fir forests
Halofsky and others	2011	Klamath Mtn.	Mixed and low severity fire regime comparison
Hessburg and Agee	2003	Inland Northwest	Historical narrative of Inland Northwest, USA forests
Hessburg and others	2007	Eastern Washington	Patch mosaic in dry and mixed conifer forests
Hessl and others	2004	Pacific Northwest	Climate relation to fire seasons
Heyerdahl	1997	Blue Mtn.	Dissertation – Climate and fire regimes
Heyerdahl and others	2012	British Columbia	Fire history to describe mixed-severity fire regimes
Klenner and others	2008	British Columbia	Determined mixed-fire regime dominated dry forests
Maruoka	1994	Blue Mtn.	Thesis – fire history – dry mixed conifer
McNeil and Zobel	1980	Crater Lake NP	Fire history – ponderosa pine and white fir
Mohr and others	2000	Klamath Mtn.	Pollen and charcoal from lake sediment cores
Morrison and Swanson	1990	Cascade Mtn.	Fire history and patch dynamics
Mote and others	1999	OR and WA	Climate variation in fire activity
Odion and others	2004	Klamath Mtn.	Fire severity mosaic in current conditions
Olson	2000	Blue Mtn.	Thesis: Fire occurrence in riparian and upslope areas
Perry and others	2011	WA, OR, and CA	Ecology of mixed fire regimes
Powell	2011	Blue Mtn.	White paper – historical fire regimes
Sensenig	2002	Southwestern Oregon	Thesis: fire history mixed conifer
Stuart and Salazar 2000	2000	Coastal Mtn. CA.	Fire history mixed conifer forests
Taylor	1993	Klamath Mtn.	History on red fir forests
Taylor	2000	Lassen Volcanic NP	Fire history and low and mixed severity fire regimes
Whitlock	1992	Pacific Northwest	Historical narrative of vegetation and climate
Williamson	1999	Blue Mtn.	Thesis: Forest structure & fire hazard in riparian areas
		Utah	
Battaglia and Shepperd	2007	Utah	Narrative on disturbance history
Heyerdahl and others	2011	Utah	Fire history – dry and mixed conifer forests
		North America	
Keeley and others	2009	North America	Fundamental fire ecology synthesis

Northern California and Klamath

Collins and Stephens (2010) conducted a fire history study within Yosemite National Park and considered this area to be influenced by the mixed fire regime. Although they noted that this tended to create a mosaic of small patches, there was also a large range of high-severity patch sizes. They also stated that topographic factors such as slope position might have influenced patch size, with the smallest patches occurring in upper slopes, lower slopes, and valleys. The larger patches tended to occur mid-slope and on flat topographic positions. They also noted that the patch size could be influenced by the underlying vegetation configuration and abundance, with shrub-dominated vegetation leading to smaller patches and fir dominated systems tending to favor larger stand replacing patches. The key point from Collins and Stephens (2010) was that although the majority of the area had a mosaic of small patch sizes and variability in topographic features influencing the fire regime, there were also large, stand-replacing patches (<15 percent of the total burned area) that were likely a part of the fire regime as well.

As we summarized the fire regimes for different areas, one constant theme appeared. In most dry mixed conifer forests, a mixed fire regime tends to be dominant, generating both high-severity stand replacing patches and low-severity patches. (Halofsky and others [2011] presented unique features, specific to the Klamath region, of the mixed severity fire regimes that could be applicable to other regions within our synthesis area [table 3.3].) There is a broad range of intermixing of diverse patches of vegetation ages and structures, resulting in high variability in fire regime parameters such as return interval, dominant drivers of fire, and subsequent fire effects. Because of the variability in topography, fuels, and the topographical influence on weather, the mixed severity regime tends to create a fine-scale mosaic of patches of vegetation, which burns at various levels of severity. Also, the variability in fire return interval creates a wide range of patch ages, structures and compositions. Accordingly, Halofsky and others (2011) infer that although these forests do have elements of high- and low-severity fire regimes, they are predominantly mixed fire regimes and are distinctly different from forests that experience low- or high-severity fire regimes. The tendency towards mixed fire regimes derives from complex topography, a broad range of soil depths, and diversity in vegetation with respect to successional stage, species composition, and horizontal and vertical structure.

Pacific Northwest Interior

Fire return intervals and intensities in the Pacific Northwest have been highly variable. Everett and others (2000) noted that the fire regime favored a mixed severity, which created a heterogeneous landscape across north central Washington consisting of patches that had burned at varying severities at different times. Small patches were created in places where surface and ladder fuels accumulated (facilitating the movement of fire into crowns); however, the pattern of these patches was not consistent and they did not appear to be a function of aspect or slope. Similarly, in southern British Columbia, Heyerdahl and others (2012) found evidence of extensive low-severity fires intermixed with small patches of high-severity fire. Again, there was no evidence supporting a link to topography, a finding consistent with what Klenner and others (2008) observed.

Powell (2011) summarized key characteristics of the historical fire regimes that occurred within the Blue Mountains, Oregon (table 3.4). The predominant fire regime is either fire regime 1 (75 percent of historical burned area) or III (15 percent of historical burned area), with fires either consisting of low severity to mixed severity fire regimes.

Table 3.3. Comparison of fire characteristics and subsequent ecosystem response between mixed and low severity fires from studies conducted in the Klamath. Adapted from Halofsky and others (2011).

Mixed-severity fires	Low-severity fires
Fire Characteristics	
The influence of topography, weather, and fuels are dominant drivers of fire behavior and effects.	Fuels are the dominant driver of fire behavior and effects
Fuel structure plays in important role in patch size effects, but periods of extreme weather can override other factors	
Occurrence of high severity fire even with a relatively short fire return interval	Short intervals between fires are primarily associated with low-severity surface fires.
Spatial mosaic of a fire tends to be reinforced through subsequent fires over the short term (<30 years), with implication for long-term landscape forest structure	Fires consume surface fuels and make additional fires less likely for a period
High amount of edge between seral stages due to repeated and spatially heterogeneous burns	Low amount of edge-between seral stages due to more homogeneous burns
Ecosystem Response	
Abundant post-fire conifer regeneration based on proximity of seed source or seed storage in soil, in all but the largest high-severity patches on the driest sites	Moderate to high conifer regeneration under intact canopies after surface fires and in small-fire created openings, with little regeneration in large openings.
Juxtaposition of early and later seral vegetation, provides habitat for a arrange of wildlife species in relatively close proximity	Limited intermixing of seral stages; early seral patches typically confined to small areas within mature forest cover.
High community resilience because of the presence of species adapted to regenerate after disturbance, spatial intermixing of seral stages, and close proximity of seed sources.	Reported delays in regeneration after repeated high severity fires and some state changes after uncharacteristically severe fire in ponderosa pine.

Heyerdahl and others (2001) noted regional variability in fire regimes. They found that the southern portion of the Blue Mountains burned more frequently than the northern portion. They suggested that this variability was influenced by latitudinal variations in climate (which affect fuel moistures), lightning frequency, summer precipitation, and snow melt patterns. These factors resulted in longer dry periods in the southern portion versus the northern portion of the Blue Mountains, consequently favoring more frequent fires. In addition to climate as a broad scale influence, the researchers also found fine-scale, topographic influences. For example, the patterns of historical fire frequency were dependent on size and juxtaposition of aspect and slopes in conjunction with natural fire barriers, which isolated or influenced fire size. By contrast, in areas without fire barriers and little variation in slopes or elevation, fire frequency did not vary with aspect or slope angle.

Table 3.4. Powell (2011) developed and summarized the historical characteristics and fire regimes for the Blue Mountains, Oregon. Fire regime V is rare in the Blue Mountains, thus it is not shown.

	Historical fire regimes[1]			
Fire regime characteristic	**I**	**II**	**III**	**IV**
Return interval (mean; years)[2]	< 25	< 35	35-100+	35-100+
FRCC: fire frequency interval (years)[3]	0-35	0-35	35-200	35-300
Fire severity on upper canopy layer[4]	Low	Replacement	Mixed	Replacement
Upper canopy layer mortality(%)[4]	≤ 25%	> 75	26-75	> 75
FRCC: fire severity name[3]	Low to mixed	Replacement	Mixed to low	Replacement
Fire intensity adjective[5]	Low	Low to Moderate	Moderate to high	High
Fireline intensity (flame length; feet)[6]	< 3	< 3	3 to 10	> 10
Fuel component driving fire spread[5]	Surface	Surface	Surface and canopy	Canopy
Ecosystem example[5]	Ponderosa pine	Grassland/shrub	Mixed-conifer	Subalpine fir
Historical burned area (%)[7]	75	5	15	5
Estimated fire size (ac)[8]	1 to 3,000	Unknown	1 to 10,000	1 to 5,000
Measured fire size (ac)[9]	2,850	Unknown	900	Unknown
Fire size variability (min-max acres)[10]	50 to 19,960	Unknown	250 to 1,940	Unknown
Fire seasonality[11]	Summer and fall	Spring and summer	Summer and fall	Summer and fall

[1] Historical fire regime is a characterization of the historical combination of fire frequency and severity under which plant communities evolved and were maintained (Schmidt and others 2002). Five fire regimes are currently recognized (Barrett and others 2010). These five groups include: I – frequent (0 to 35 years), low and mixed severity; II – frequent (0-35), replacement severity; III – 35 to 200 years, low and mixed severity; IV- 35 to 200 years, replacement severity; and V – 200+ years, replacement severity. The majority of the dry mixed conifer forests in our synthesis area are classified as fire regime group I (frequent 0 to 35 years, low and mixed severity) and group III (35 to 200 years, low and mixed severity)

[2] Fire return interval (years) is the frequency between successive fire events; values based on Hall (1976), Heyerdahl and Agee (1996), Maruoka (1994), and Schmidt and others (2002).

[3] FRCC (fire regime condition class) is a process for evaluating whether current conditions have departed from historical reference conditions and, if so, the magnitude of the departure.

[4] Fire severity on upper canopy layer is the effect of fire on dominant plants: no more than 25 percent of upper canopy layer plants are killed by low-severity fire, whereas 75 percent or more are killed by high-severity fire; moderate-severity fires have survival percentages between these extremes (the 25 percent and 75 percent mortality thresholds were established by FRCC; see Barrett et al. 2010, page 99).

[5] Fire intensity, fuel component, and ecosystem examples were taken from Keeley and others 2009 (table 1).

[6] Fireline intensity refers to the energy release rate of a fire. Since intensity is generally proportional to flame length, fireline intensity is frequently expressed as a flame length, in feet. Information was from Agee (1996).

[7] Historical burned area is an estimate of annual burned area (percent) for the Blue Mountains area prior to Euro-American settlement (defined as pre-1850); information adapted from Agee (1996).

[8] Estimated fire size provides an indication of average wildfire extent (in acres) for the Blue Mountains, as derived using an expert panel approach and involving 50 employees from the Malheur, Umatilla, and Wallowa-Whitman National Forests (Johnson 1993).

[9] Measured fire size provides an indication of average wildfire extent (in acres) from a Blue Mountains fire history study (Heyerdahl and Agee 1996; Heyerdahl 1997).

[10] Fire size variability shows how historical wildfire extent varied (in acres) from a Blue Mountains fire history study (Heyerdahl and Agee 1996; Heyerdahl 1997).

[11] Fire timing refers to the typical season of wildland fire. Information was taken from Agee (1996).

Northern and Central Rocky Mountains

Across dry mixed conifer forests in Idaho and western Montana, the average fire return interval (FRI) was as low as 6 years, with many sites experiencing fires every 11 to 15 years, on average (Heyerdahl and others 2008) (table 3.5). The Lowman Research Natural Area on the Boise National Forest (southern Idaho) was unusual in that its average FRI was 29 years. Even more striking is the exceptionally broad range of FRI among sites in this forest—from one year on many sites to over 20 years between fires on others, with some exceeding 30 years. Arno (1976) noted that in the Bitterroot National Forest (western Montana), fires burned on southern aspects more frequently and killed ponderosa pine saplings and torched large Douglas-fir trees. Northern aspects burned less frequently, but more intensely and the dense Douglas-fir stands, common at such sites, tended to carry crown fires. However, old and large western larch, ponderosa pine, and/or Douglas-fir frequently survived within a matrix of crown killed forest.

Table 3.5. Fire histories quantified by Heyerdahl and others (2008) from sites in mixed-dry conifer sites in Idaho and western Montana (see figure of locations) and Heyerdahl and others (2012) in Utah. Size of the area where data were collected from individual trees. Trees sampled, are the number of trees that were cross-dated and used to calculate the average and range of fire occurrence.

Site name	Location National Forest	Area size	Trees sampled	Fire occurrence (Years) Mean	Fire occurrence (Years) Range
Idaho and Montana					
Sheafman Creek	Bitterroot	35	41	11	2 to 30
Sawmill Creek RNA	Bitterroot	109	32	15	3 to 32
Wash Creek	Boise	77	25	11	1 to 22
Bannock Creek	Boise	69	30	8	3 to 19
Warm Springs Ridge	Boise	37	27	9	3 to 20
Lowman RNA	Boise	57	9	29	14 to 47
Crane Lookout	Flathead	45	18	16	7 to 31
Holland Lake Road	Flathead	94	19	15	3 to 30
Sheldon Flats	Kootenai	89	29	6	2 to 17
McMillan Mountain	Kootenai	20	32	12	4 to 25
Hunter Point	Kootenai	77	25	14	2 to 27
Blue Mountain	Lolo	82	36	6	1 to 17
Butler Creek	Lolo	5	38	8	3 to 23
McCormick Creek	Lolo	367	17	13	3 to 30
Sophie Lake	Montana	32	46	6	1 to 15
Keating Ridge	Nez Perce	10	22	14	3 to 26
Cove Mountain	Nez Perce	30	25	18	3 to 46
Poverty Flat	Payette	45	33	12	3 to 26
Corona Road	Private	7	26	11	4 to 25
Flannigan Creek	Private	69	25	6	2 to 24
Friedorf Gulch	Salmon-Challis	116	31	12	1 to 37
Utah					
Snake Range	Great Basin National Park	1569	103	19	1 to 62
Boulder Mountain	Dixie	1963	95	30	5 to 110
Beaver Creek	Fishlake	2837	164	34	2 to 100
Wah Wah Mountains	Bureau of Land Management	1593	16	20	2 to 86
Indian Creek	Fishlake	624	34	28	6 to 75

The Black Hills of South Dakota and Wyoming are unusual in their isolation. They are disconnected from other major mountain ranges and they contain forests that are composed predominantly of ponderosa pine at the far eastern edge of its range. However, patches of dry mixed conifer forests with white spruce, paper birch, and quaking aspen can occur, particularly in protected areas, have deep soils, and occur at elevations above the dry ponderosa pine forests of the Black Hill. Mean FRIs in these dry mixed conifer forests ranged between 20 to 35 years (Brown 2003; Brown and others 2008). The Black Hills tend to have a mixed fire regime dominated by surface and some passive crown fire (Brown and others 2008)

Utah

There is considerable diversity in the historical fire regimes within the dry mixed conifer forests in Utah. In ponderosa pine forests, low- to moderate-severity surface fires dominated with very few occurrences of crown fires. As productivity increases and dry mixed conifer forests became more common (where Douglas-fir and white fir can potentially occur), mixed severity and stand replacing fires tended to occur (Battaglia and Shepperd 2007; Bradley and others 1992). Kilgore (1981) noted that topography, weather, stand structure, and fuel loading all contributed to generate a variety of different patterns of fire intensity and frequency; in other words, the result was a much more mixed and variable fire regime. Consequently, a mosaic of different fuel types created a mosaic of different fire outcomes. In some places, the fire resistant species such as ponderosa pine and larger Douglas-fir trees survived these fires and were dominant.

Wildfire size and climate variability were recently studied by Heyerdahl and others (2011) (table 3.5). They found that many of these areas where they documented fire history via fire scar evidence experienced range of fire severities through time and when analyzed in aggregate, it was possible to gain insight about fire size. Large fires occurred when summers were drier than average and were more likely during La Nina years, whereas no fires occurred in years that were wetter than average. Recently, Heyerdahl and others (2011) summarized fire histories on many sites in the Great Basin and found that sites within the dry mixed conifer forests had mean FRIs of 19 to 34 years; however, the FRI range was large: 2 to 86 years in the Wah Wah Mountains and Beaver Creek and 2 to 100 years on the Fishlake National Forest of Utah.

Climate Patterns

This section was included to promote understanding of how there may be non-random processes behind the weather that, when combined, generate an impression of randomness. These processes have left a residue of signals (warm periods, dry periods, wet periods, times with lots of fires, and times with few) that we may have mistakenly ascribed entirely to other factors (for example, the onset of aggressive fire suppression, a gravitation toward using wildfire to meet resource objectives, or changes in fire suppression policies). These may all indeed be factors, but knowing more about the underlying climate may help us place them in better context. It may also help us recognize that there are factors that we cannot control but deserve consideration in making informed decisions concerning fuel treatment planning.

Changes in ocean currents and sea surface temperatures influence the jet stream, which alters precipitation and temperature patterns, which in turn influence fire occurrence and extent. Two specific phenomena that influence moisture patterns in the western United States are the El Nino/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). Our goal in this section is to describe how climate plays a role in the temporal pattern in fire and other disturbances.

For ENSO, variation in the surface temperature and air surface pressure in the tropical Pacific Ocean determines whether an El Nino or a La Nina event occurs. When the ocean surface temperature is warm in the eastern Pacific Ocean and the air surface pressure is high in the western Pacific Ocean, it is known as an El Nino event. When the ocean surface temperature is cold in the eastern Pacific Ocean and the air surface pressure is low in the western Pacific Ocean, it is known as a La Nina event. El Nino and La Nina events occur on average every 2 to 7 years. La Nina events usually occur for 1 to 3 years but occur half as frequently as El Nino events. El Nino events tend to last 9 to 12 months. These events alter temperature and precipitation patterns across the globe. In the United States, the largest impact is during the winter months. ENSO alters the location of the jet stream, which changes precipitation and temperature patterns across the western United States. Each region within our synthesis area is impacted in different ways by ENSO (table 3.6). These differences highlight the importance of understanding regional differences in large-scale climatic patterns when discussing fire regimes, regeneration dynamics, and tree growth within the dry mixed conifer forests because these patterns relate to the potential fire season.

Table 3.6. Seasonal patterns of temperature and precipitation for strong El Nino and La Nina years for different locations within our synthesis area. La Nina is characterized by unusually cold ocean temperatures in the eastern equatorial Pacific and El Nino is characterized by unusually warm ocean temperatures in the equatorial Pacific.

		Temperature (departure from normal)				Precipitation (departure from normal)			
Locations	**Climate pattern**	**Oct. – Dec.**	**Dec. – Jan.**	**Jan. – Mar.**	**Apr. – Jun.**	**Oct. – Dec.**	**Dec. – Jan.**	**Jan. – Mar.**	**Apr. – Jun.**
Northern California	El Nino	Normal to below	Normal to above	Normal to above	Above	Normal	Above	Above	Above
	La Nina	Normal	Normal to below	Below	Normal	Above	Normal	Normal	Normal
Eastern Cascades	El Nino	Normal	Above	Above	Above	Below	Below	Normal	Above
	La Nina	Normal	Normal	Below	Below	Above	Above	Above	Below
Northern Rocky Mountains	El Nino	Above	Above	Above	Above	Below	Below	Below	Above
	La Nina	Normal	Normal	Normal to below	Below	Above	Above	Above	Normal to below
Black Hills	El Nino	Normal	Above	Above	Above	Normal	Below	Normal	Above
	La Nina	Above	Above	Normal	Below	Normal	Normal	Normal	Normal
Northern Utah	El Nino	Normal	Normal	Above	Above	Normal	Below	Below	Normal
	La Nina	Above	Normal	Normal	Normal	Above	Normal	Normal	Normal
Southern Utah	El Nino	Normal	Normal	Above	Above	Above	Normal	Above	Above
	La Nina	Above	Normal	Normal	Normal	Below	Below	Below	Below

El Nino

To demonstrate how El Nino impacts a specific region within a state, NOAA has developed a website that provides maps of precipitation and temperature departures for each climate division within a state: (http://www.cpc.ncep.noaa.gov/products/predictions/threats2/enso/elnino/index.shtml). NOAA also provides maps of La Nina impacts on temperature and precipitation on specific regions: (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/usdivtp/writeup.shtml#usmaps).

In Northern California, fall temperatures are normal to cooler than normal and the precipitation is normal during La Nina years. Throughout the winter, temperatures are normal to warmer, but precipitation increases. In the spring, the region is warmer and wetter. In Washington and Oregon, fall temperatures are normal but it is dry. In early winter, it is warm and dry, but by late winter, normal moisture is expected. By spring, the region is warmer and wetter. The northern Rocky Mountains experience warm and dry weather from fall through the end of winter. By spring, the region is warmer and wetter than average. In fall, Utah experiences normal temperatures and normal precipitation in the northern portions, but increased precipitation in the southern areas. Early winter has normal temperatures but it is dry in the northern areas and receives normal precipitation in the southern areas. By late winter, it is warmer in both regions of Utah, but the northern portions are dry and the southern portions are wet. By spring, it is warmer in both regions of Utah; the northern portions experience normal precipitation but the southern portions are moist (table 3.6).

The Pacific Decadal Oscillation is similar to the El Nino Southern Oscillation in climatic variability, but instead of only lasting a few years, the PDO persists for 20 to 30 years. For PDO, variation in the surface temperature and air surface pressure north of 20°N in the Pacific Ocean determines whether PDO enters the “warm/positive” or the “cool/negative” phase. During the warm phase, the western portion of the Pacific Ocean cools and the eastern portion of the Pacific Ocean (along the west coast of the United States) is warm. The strength of an ENSO event can depend on the PDO phase (Brown and Comrie 2004).

Studies located within the synthesis area identified multiple spatial and temporal sources of variation that influence fire frequency (table 3.6). On the broadest scale, the cycles of drought driven by the Pacific Decadal Oscillation (PDO) and El Nino/Southern Oscillation (ENSO) are important contributors to variation in fire frequency. One study noted that large fires tend to occur more frequently during the positive phase of the PDO than during the negative phase in the Inland Northwest (Hessl and others 2004). Morgan and others (2008) verified this pattern for the northern Rocky Mountains. They found that fires burned large areas across the geographic region during what they call "regional fire years." Up to 74 percent of the total fire extent occurred during these regional fire years, which occurred early and late in the last century. Six regional fire years occurred between 1910 and 1934 and five regional fire years occurred between 1988 and 2003. The PDO index was positive during nine of the 11 regional fire years. These years were characterized by warm springs followed by significantly warm, dry summers. The mid-20th century period, which limited regional fire years (1935–1987), generally had cool springs, negative PDO, and a scarcity of extremely dry summers. The researchers hypothesized that the PDO influences multidecadal winter moisture, subsequently accounting for long-term variation in fine fuel conditions and fuel abundance (they also noted that this result should be viewed cautiously due to potential errors in reconstruction of the PDO).

Whereas ENSO is an important driver of fire in southwestern ponderosa pine systems (Swetnam and Betancourt 1990, 1998), fire history studies in the Inland Northwest have shown more ambiguous results (Hessl and others 2004; Heyerdahl and others 2002; Morgan and others 2008). Some researchers have suggested that within the Pacific Northwest, the ENSO relationship to fire recurrence is not as strong as in the Southwest because fuel structures are not as responsive to climatic variability associated with ENSO temporal or seasonal variation (and also because the ENSO signal may be weaker and therefore not as strong a driver in the Northwest) (Hessl and others 2004).

Variation in Fuels, Topography, and Weather

Brown and Smith (2000) recognized that with respect to impacts on forests, mixed severity fire regimes have three defining characteristics: (1) many trees are killed by surface or smoldering fire, but also many fire-resistant, large trees survive; and (2) severity varies between understory and stand-replacement fires, which create a fine-grained pattern of young and older trees—a pattern most likely explained by: (i) variations in fire weather, such as diurnal cycling in fire intensity over a multi-day fire; (ii) variation in topography, fuels, and stand structure within a fire perimeter; and (iii) the severity at a given location varies over time with individual fires alternating between understory burns and stand-replacing fires (Kilgore 1981).

Arno (1980) noted that mixed severity regimes involve a variety of fire intensities. When fire weather is severe, for example, when strong winds are blowing, surface fires can convert to crown fires and cover vast areas. The largest patches on the Biscuit Fire occurred on days with strong prevailing winds out of the northeast (Halofsky and others 2011). Nearly all of the growth and extreme fire behavior exhibited on the Hayman Fire, Colorado in 2002 occurred on a day when average relative air humidity was below 8 percent, maximum wind gusts were 84 miles per hour, and the Haines Index was 6 (Graham 2003). Under these conditions, no fuel treatment had much affect on severity or direction, nor would any conceivably realistic treatment have made much difference (Finney and others 2003).

Arno (1980) noted another characteristic of mixed fire regimes—under moderate weather conditions, ground fires creep and smolder with occasional flare-ups; however, any given fire can burn at several intensities and severities, depending on fuels (composition and structure), topography, and weather. Consequently, a single fire can produce a mosaic of fire effects. Several of the fire history studies we summarized describe mixed fire regime outcomes as a mosaic of severities and patches of different compositions and structures, and some link this to complex topography. In his botanical report, Leiberg (1897) mentioned riding through vast areas of the northern Rocky Mountains where fires smoldered. Dillion and others (2011) also found that topography (elevation, slope, aspect, position, complexity) was consistently more important in predicting fire severity than climate or weather variables across the Inland Northwest and northern Rocky Mountains.

Mixed fire regimes are closely related to fuel moisture. Jolly (2007) concluded that fire behavior is highly sensitive to live fuel moisture, and noted that wind speed and direction, air relative humidity, solar radiation, and air temperature can indirectly change the fuel moisture content, as well as contribute directly to fire spread. In northern Idaho, topography forms a fine-grained mosaic, while vegetation spans a moisture continuum from mesic western redcedar in the draws to xeric ponderosa pine on the ridges. This topographic and vegetation diversity translates into diverse environments with differing soil moisture dynamics, and most likely, live and dead fuel moistures. Moreover, the ratio between live fuel loading and dead fuel loading can also influence fire behavior, and likely varies with composition and successional stage. For example, in the Bitterroot fires in western Montana, some areas with high live fuel loadings did not burn, while the surrounding forest experienced stand replacing fire (Jain and Graham 2007).

The key point is that mixed fire regimes are complex (Arno 2000; Halofsky and others 2011; Perry and others 2011; Schoennagel and others 2004). Fuels and topography play a major role in fire behavior and effects. Accordingly, in planning for fuel treatments, a single prescription is rarely sufficient; a diversity of vegetation structure and compositions are important elements to incorporate. It is also important to note topography and the variability in vegetation. Even the best designed fuel treatments may not be effective under extreme weather conditions, exemplified by strong wind and low air relative humidity, which can produce fire behavior that overwhelms otherwise effective treatments.

Vegetation Autecology and Fire Tolerance

The combination of disturbances and environmental heterogeneity favors multiple tree species, each with different tolerances and adaptive traits. Understanding fuel dynamics is critical for planning, implementing, and measuring success of fuel treatments to meet a variety of objectives. In this synthesis we were unable to summarize every potential adaptation a particular species may have; however, we do provide some examples of how different species have evolved to take advantage of opportunities to regenerate, grow, and develop. This section summarizes some key autecological characteristics of the key tree and shrub species, with an emphasis on fuel dynamics.

Autecology

Autecology is the study of environmental factors, including disturbance, and how they affect particular plant species. Comparative autecology is when multiple species are ranked by their resiliency to environmental factors.

Species develop a variety of adaptive traits (species autecology) that make them resilient to a range of disturbances over their life and help them to regenerate, grow, develop, and thrive (table 3.7). There are a few key elements that may be of interest to fuel management. Canopy openings have a strong influence on the type of species that are favored. Because early-seral species have adapted to regenerate after disturbances in open environments with high light availability, they tend to be the most sensitive to canopy opening size and are the most successful in large openings. However, it is widely assumed that early-seral species require very large openings when in fact many of these species are well-adapted to a range of post-fire environments, including those with residual snags and limited residual overstory biomass (Jain and others 2004; Haig and others 1941).

Table 3.7. Species autecology and resilience to climate change tolerances (Minore 1979).

Species	Light conditions for establishment	Frost tolerance	Heat tolerance	Adaptation to warm average temperatures	Drought tolerance	Dry conditions
Quaking aspen	Moderate-high	—	—	—	—	—
Douglas-fir	Moderate	Low-moderate	Moderate	Moderate-high	Moderate-high	Moderate
Grand fir	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Engelmann spruce	Low-moderate	High	—	Low	Moderate	—
Jeffrey pine	—	Moderate-high	High	—	High	—
Lodgepole pine	Low	High	Moderate	Low-moderate	Moderate-high	—
Oregon white oak	—	—	—	High	High	High
Pacific madrone	—	—	—	—	—	High
Ponderosa pine	Moderate-high	Moderate-high	High	High	High	Moderate-high
California red fir	Low to moderate	Moderate-high	Moderate	Moderate	Low	Low
Subalpine fir	Moderate	Moderate	Moderate	Low	Moderate	Low
Sugar pine	High	Moderate	High	Moderate-high	Moderate	High
Tanoak	Moderate	—	—	—	—	—
Western hemlock	—	Low	Low	Moderate	Low-Moderate	Low-moderate
Western larch	High	—	Moderate-high	Moderate-high	Moderate	Moderate
Western red cedar	Low	Low-moderate	Low	Moderate	Moderate	Low
Western white pine	Moderate to high	High	Moderate	Moderate	Moderate	Low
White fir	Moderate	Moderate	Moderate	Low	Moderate	Low

For example, ponderosa pine in the Black Hills can regenerate under very dense canopies, even up to 70 percent canopy closure; however, rate of growth and individual tree vigor can be quite poor in these circumstances. Western white pine, which has moderate to high tolerance for low light conditions, can regenerate at 75 to 55 percent canopy closure and species such as grand fir can regenerate in places with approximately 85 percent canopy closure or more (Jain and others 2004). If the objective is to conduct a thinning and sufficient growing space is available post-treatment, true firs can readily regenerate naturally and create unwanted ladder fuels, decreasing the long-term effectiveness of the treatment. However, acknowledging the influence of opening size on tree growth can be an advantage. For example, higher overstory densities slow growth. Thus, a tree that is growing in the understory will take a longer period of time to become a ladder fuel, extending the useful life of a fuel treatment.

Shrubs have similar adaptive traits (table 3.8). For example, ninebark is adapted to establish quickly after a disturbance and is most successful in larger openings–it sprouts and increases after fire, and is very intolerant of shade. Thus, if canopy density is decreased on sites that have ninebark, they will respond quickly and profusely, creating a surface fuels that may or may not be desired. When the overstory is manipulated, growing space is released in the understory, creating conditions for the establishment and regeneration of vegetation that influences surface fuels. Table 3.8 lists the most common shrub species within the synthesis area and summarizes their adaptations to the environment.

Soil disturbance can influence the trajectory of vegetation regeneration, growth and development. Depending on the type of soil substrate, mineral, organic, or blackened surfaces can favor the regeneration or sprouting of a particular species. Although all species can regenerate on all substrates, depending on location, specific substrates can favor one species over another. For example, grand fir and western redcedar can readily regenerate on organic material such as litter and duff. In contrast, western larch prefers mineral soil or blackened surfaces (such as those present after fire). Western white pine can regenerate on all substrates quite readily. Shrubs sprout or regenerate from seed and their adaptive traits vary depending on the location and type of substrate as well as the type of disturbance.

Table 3.8. Understory characteristics in fire dominated forests within the Northwest dry mixed conifer (FEIS http://www.fs.fed.us/database/feis/plants/index.html.

Plant name	Fire tolerance	Establishment	High severity fire	Low severity fire	Recover to pre-fire levels	Shade tolerance	Drought	Rooting habit	Mature height (ft)
Forbs									
Common beargrass	High	Seed	Decrease	Increase	9-36 years	Intermediate	Medium	Deep	5
Twinflower	Low	—	Killed	Killed	6 years	Tolerant	—	Shallow	0.5
Grasses									
Bluebunch wheatgrass	Low	Seed/sprout	—	Increase	—	Intolerant	High	Deep	3
Idaho fescue	Medium	Seed	Decrease	Decrease	Up to 25 years	Intermediate	Low	Shallow	2
Low shrubs									
Kinnikinnick	Low	Sprouting	—	—	Slow	Intermediate	High	Deep	0.5
Medium shrubs									
Black sagebrush	Low	Seed	Killed	Decrease	15-60 years	Intolerant	High	Shallow	2
Common snowberry	High	Sprouting	Decrease	Increase	1 year	Intolerant	High	Shallow	3
Greenleaf manzanita	High	Seeding	Increase	Increase	1 year	Intermediate	High	Deep	6
Mallow ninebark	High	Sprouting	Increase	Increase	—	Intolerant	High	Deep	15
Mountain big sagebrush	None	Seeding	Killed	Killed	15-20 years	Intolerant	High	Deep	4
Serviceberry	High	Sprouting	Increase	Increase	1 year	Intermediate	Low	Deep	15
Snowbrush ceanothus	High	Seed/sprout	Increase	Increase	1 year	Intolerant	Low	Deep	10
Spiraea	Medium	Sprouting	Increase	Neither	1 year	Tolerant	Low	Shallow	3
Thinleaf huckleberry	High	Sprouting	Increase	Increase	3-7 years	Intermediate	Low	Deep	4.5
Tall shrubs									
Gambel oak	High	Sprouting	Increase	Increase	18 years	Intolerant	Low	Deep	40
Rocky Mountain maple	High	Seed/sprout	Increase	Increase	5 years	Intermediate	Medium	—	30
Scouler's willow	High	Seed/sprout	Increase	Increase	5 years	Intermediate	Medium	Deep	50
Vine maple	Medium	Sprouting	Decrease	Decrease	2-25 years	Tolerant	Low	Shallow	20
Invader species									
Cheatgrass	Medium	Seed	Increase	Increase	1 year	Intolerant	High	Shallow	2
Canada thistle	Medium	Seed/sprout	Increase	Increase	2-9 years	Intermediate	Low	Deep	6
Spotted knapweed	High	Seed/sprout	Increase	Increase	1 year	Intolerant	High	Shallow	3

All species have evolved to take advantage of conditions that favor their regeneration abilities because the plant that captures a site first dominates that site. In addition, different species have adapted to the conditions that are created by the predominant disturbances that maintain the forest. Considering the differences among the different plant species and recognizing the effect fuel treatments have on the growing environment will provide a basis for predicting the type of surface fuels that will be facilitated by a given treatment, the likely growth rate of that fuel, and ultimately treatment effectiveness and longevity.

In addition to having different adaptations to the physical characteristics of the sites where they grow, many species have developed adaptive strategies to resist disease and insect infestations (table 3.1). This is particularly true for the early-seral tree species such as western white pine, western larch, sugar pine, and ponderosa pine. In contrast, species such as grand fir, white fir, and Douglas-fir tend to be comparatively welcoming hosts to numerous native insects and diseases (Hagle and others 2003; Rocky Mountain Region, Forest Health Protection 2010) (table 3.1). Pine beetle can generate prodigious quantities of dead wood (standing and down) and many species of trees are susceptible to this insect. However, susceptibility varies with age and tree density. For example, it is well recognized that ponderosa pine is less susceptible to bark beetle infestation when stem density is between 80 to 100 ft^2 of basal area per acre (Fettig and others 2007; Schmid and others 2007). Thus, current conditions (age, size, and species) will dictate particular treatment characteristics that may favor resilience. Silvicultural knowledge that incorporates these nuances and acknowledges treatment combinations that favor resilient combinations of size and species compositions are a part of fuel treatment development.

A variety of species have adapted to different levels of fire resistance (Arno and Allison-Bunnell 2002; Perry and others 2011) (table 3.9). Ponderosa pine, western larch, Jeffrey pine, and Douglas-fir are all very tolerant of fire when they are mature (table 3.9). By the time trees of these species become middle-aged (~100 years), they tend to have thick bark, which protects the cambium from heat generated by low intensity surface fires. Also, these trees tend to be tall and self-prune, making their crowns resistant to ignition by surface fires. Many of the species within the dry mixed conifer forests—such as grand fir, white fir, sugar pine, western redcedar, and western white pine—have moderate tolerance. For shrubs, many of the species such as ninebark, spirea, and serviceberry can quickly recover after fire (table 3.9) through vigorous production of fast growing sprouts.

Conclusion

Dry mixed conifer forests are complex. The combination of disturbances, topography, weather patterns, and vegetation creates a diversity of forest structures and compositions. Therefore, there are not one, two, or three sets of desired future conditions, but rather a mosaic of many different conditions. Thus, the dry mixed conifer forests offer many challenges. However, recognizing the forces that influence and maintain these forests is an important step. With complexity comes challenges but with variability there can be diverse opportunities to create a variety of forest structures, compositions, and fuels that achieve integrated fuels management objectives.

Table 3.9. Tree characteristics important to surviving a fire and an overall species resistance to fire rating (Flint 1925; Starker 1934; Minore 1979; FEIS (http://www.fs.fed.us/database/feis/plants/index.html). Many of these characteristics are the most effective when trees are mid-aged to old when the bark begins to become thick.

Species	Basal bark thickness	Canopy base ht.	Canopy density	Canopy habit	Size of buds	Needle length	Sprout	Tree size	Fire resistance	Burn characteristics	Lichen receptivity	Root habit
Aspen	Medium	—	—	—	—	—	Yes	Mature	Low/Med	—	Low	Shallow
Douglas-fir	Thick	Low	Mod.	Mod.	Medium	Medium	No	Pole	High	High	Mod.-high	Deep
Grand fir	Medium	Low	High	Dense	Medium	Medium	No	Mature	Medium	Mod.	Low-mod.	Shallow
Engelmann spruce	Thin	Low	High	Dense	Medium	Medium	No	None	Low	High	High	Shallow
Jeffrey pine	Thick	—	—	—	Medium	Long	No	Pole	High	High	—	—
Lodgepole pine	Very thin	Mod.	Low	Open	Medium	Short	No	Mature	Medium	Low-mod.	Low	Shallow to deep
Oregon white oak	Thin/Med	—	—	—	—	—	Yes	Pole	Medium	—	—	—
Ponderosa pine	Thick	Mod.	Low	Open	Large	Long	No	Pole	High	High	Low-mod.	Deep
California red fir	Thick	Mod.	High	Dense	—	—	No	—	Medium	High	—	—
Subalpine fir	Very thin	Low	High	Mod.	Medium	Medium	No	None	Very low	High	Mod.-high	Shallow
Sugar pine	Thick	—	—	Open	Medium	Medium	No	Mature	Medium	Mod.	Low	Medium
Tanoak	Medium	—	—	—	—	—	Yes	Pole	Medium	—	—	—
Western hemlock	Medium	Low	High	Dense	Small	Short	No	None	Low	High	High	Shallow
Western larch	Very thick	High	Low	Open	Small	Medium	No	Pole	High	Low	Mod.-high	Deep
Western red cedar	Thin	Low	High	Dense	Small	Short	No	Mature	Medium	Low-Mod.	Mod.	Shallow
Western white pine	Medium	High	Mod.	Mod.	Medium	Medium	No	Mature	Medium	Mod.	Mod.	Medium
White fir	Thin	Low	High	Mod.	—	—	—	—	—	Mod.	Low-mod.	—

Further Reading

The following literature provides a synthesis on disturbances we thought would be of interest to our readers.

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Fettig, Christopher J.; Klepzig, Kier D.; Billings, Ronald F.; Munson, A. Steven; Nebeker, T. Evan; Negrón, José F.; Nowak, John T. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. Forest Ecology and Management. 238(1-3): 24-53.

Hessburg, Paul F.; Mitchell, Russel G.; Filip, Gregory M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

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Rippy, Raini C.; Stewart, Jane E.; Zambino, Paul J.; Klopfenstein, Ned B. Tirocke, Joanne M.; Kim, Mee-Sook: Theis, Walter G. 2005. Root diseases in coniferous forests of the Inland West: potential implications of fuels treatments. Gen. Tech. Rep. RMRS-GTR-141. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 32 p.

Chapter 4

Actions and Impacts of Past Management

Chapter Rationale

The purpose of this chapter is to provide a history of actions and impacts that have influenced the forests of today.

- How have human impacts altered dry mixed conifer forests?
- Humans are part of the dry mixed conifer forests; thus what can be learned from the past actions to inform decisions for the future?

Introduction

Humans have had an influence on mixed dry conifer forests for millennia. For example Native American burning, fire suppression and exclusion, animal grazing, and timber harvests have all contributed to the current structure and characteristics of dry mixed conifer forests. Many of these actions benefited the dry mixed conifer forests and added to their resilience. However, due to shortsightedness or a failure to recognize the role of disturbance in maintaining these forests, past management activities have also altered these forests in ways that have decreased their resilience. Plant compositions have shifted in some locations. There are sites where stand density has increased when compared to historical conditions; leading to an increase in fire hazard. Soil chemical and physical properties have changed with the buildup of excess organic matter. Non-native plants have been introduced that have replaced native plant species. The introduction of diseases such as white pine blister rust has altered the role of keystone species in today's forests. Although important components of these forests for creating diversity, insects and diseases are occurring over larger extents; with homogeneity in forest species composition and structure, they are becoming a continuous disturbance rather than playing their historical endemic role. Obviously, these types of changes have also had profound implications for fire regimes and most likely these regimes will not return to historical frequency and severity throughout the entire forest type.

Humans are part of the dry mixed conifer forests and, for that matter, all of the forests of the Northwest. They will continue to influence these forests into the future. Our objective in this chapter is to promote discussions concerning lessons learned from the past and how they can influence what we do in the future in forest management, including the implementation of fuel treatments. In this chapter, we briefly cover some of the influences of past management activities on the forests and describe the consequences of these actions on dry mixed conifer forests. We finish with some views of how the past can allow us to make more informed decisions concerning future management strategies.

Human Influence on Dry Mixed Conifer Forests

Cultural burning by American Indian tribes played a large role in fire regimes throughout the region (Botkin 1990; Stewart 2002). American Indians used fire to influence the character of the landscape. Fire was used to promote a diversity of habitats and increased edge effect, which provided security and stability (Boyd 1999; Pyne 1982, 1984; Stewart 2002; Williams 2001). Like hunter-gather societies the world over, most American Indian groups rarely extinguished their campfires and signal fires; they merely abandoned them and some eventually spread over large areas (Pyne 1982). Fire was used to enhance hunting opportunities by increasing forage quality and to drive game into impoundments, narrow chutes, rivers or lakes, or over cliffs. Burning was used to create and enhance conditions for growing food and medicinal plants and basketry materials, such as camas, berries, tarweed, beargrass, and willows (fig. 4.1). American Indians used fire to collect and roast crickets, grasshoppers, and Pandora moths or collect honey from bee nests as well as reduce insect pests, rodents, and poisonous snakes.

For tribes with horses, burning enhanced pasturage. American Indians used fire to maintain travel paths across mountains. Fire was a tool of war, used to deprive enemies of hiding places in tall grass or dense thickets of dense vegetation. It was also used for escaping from enemies and signaling. In addition, fire was used to shape canoes, fell trees, and shape weapon shafts and bows. For tribes that used ceramics, firing the clay was an essential part of the manufacturing process. Lewis and Clark even documented American Indians using fire as a form of entertainment in the Rockies by torching fir trees (Pyne 1982). Despite all these uses, American Indian use of fire was not ubiquitous or evenly distributed. However, in the dry mixed conifer forests of our synthesis area, fire was an important tool for American Indian tribes (Stewart 2002).

The influence of American Indians started to change with the introduction of new diseases such as smallpox, yellow fever, and malaria, which decimated many tribes–often well before Euro-American settlers appeared on the horizon (Mann 2011). Moreover,

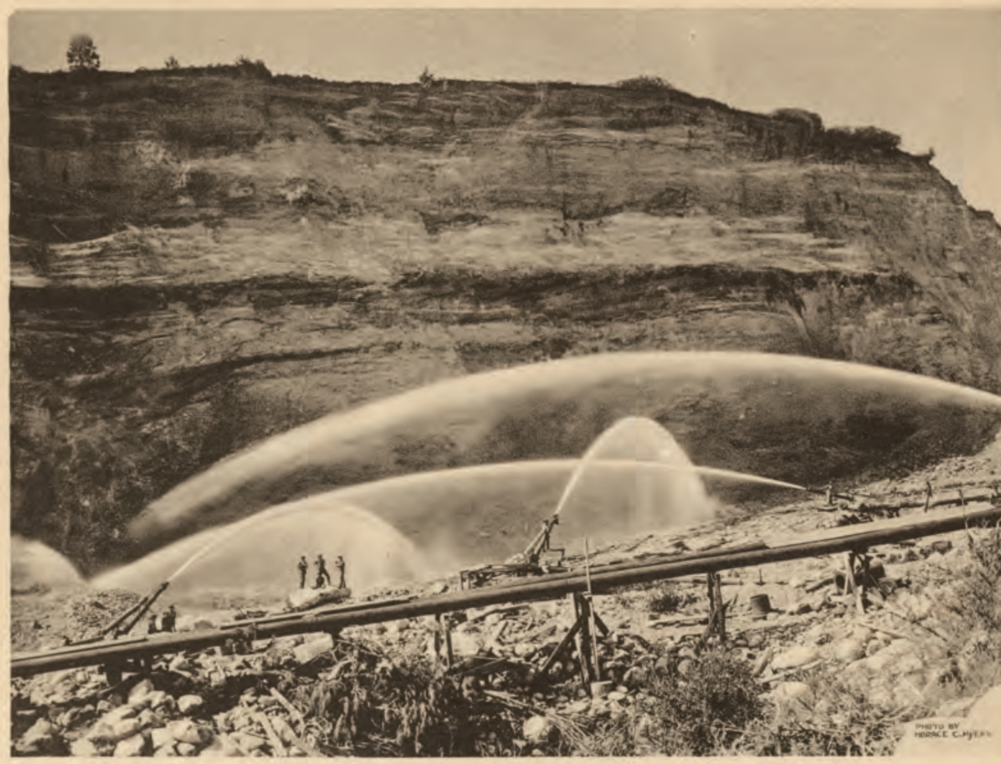
Figure 4.1. American Indians used fire to provide habitat for a variety of different uses including perpetuating important plants. The piyake gatherer 1910: Woman in long dress and bandana stooped over collecting piyake (roots) with hand scythe, leather basket at waist, trees in background. Library of Congress, Prints and Photographs Division, Edward S. Curtis collection. [reproduction number: LC-USZ62-47003].

with the arrival of Europeans, American Indian lives were changed by the introduction of a wide variety of plants and animals, advanced metallurgy, advanced weaponry, the fur trade, livestock grazing, and treaties—all of which had major consequence on native cultures and populations (Pyne 1982; Williams 2001; Mann 2011).

As settlers moved into the West during the 1800s, the forests and fire regimes of the region were quickly transformed by the effects European settlement had on American Indians and by the creation of settlements and other uses of the land (fig. 4.2). Resource extraction has always been a draw of people to the region. The discovery of gold and silver brought thousands of miners to the region, and led to the establishment of towns and associated hotels, restaurants, general stores, and other business ventures to support the miners. Mining, although concentrated in areas such as Idaho City, Boise Basin, and Coeur d'Alene Mountains in Idaho, Anaconda in Montana, and the Black Hills in South Dakota, contributed to changes in the dry mixed conifer forests (fig. 4.3). More importantly, mining contributed to settlement and land development, and the associated use of federal forest lands to support those activities.

The impacts of overgrazing by cattle, sheep, and horses, similar to other locations within the western United States, influenced dry mixed conifer forests, particularly those areas that were adjacent to preferred rangelands, riparian areas, ridge tops, and meadows (Covington and others 1994; Johnson and others 1994). Grazing had its greatest impact from overgrazing between the mid-1800s and early-1900s when grazing was unregulated (fig. 4.4). Several rangeland researchers have documented many adverse effects of excessive livestock grazing. Undesirable ecological effects include introduction and spread of invasive plants, compaction and displacement of soil, reduced water infiltration, increased erosion, and changes in plant community species composition and diversity (Belsky and Blumenthal 1997; Bunting and others 2003; Cottam and Evans 1945; Daubenmire 1940; Griffiths 1902). The reduction in forage (grass) has diminished and woody vegetation has increased, changing fire regimes from high frequency, low severity to low frequency, high severity (Belsky and Blumenthal 1997; Bunting and others 2003; Irwin and others 1994).

Figure 4.2. Settling the West, altered land uses. Camp 120, Eagle Lake, Sierra Nevada's 1860. Photograph obtained from Library of Congress, Prints and Photographs Division, Daniel A. Jenks, artist, [reproduction number: LC-DIG-ppmsc-04821].



PLACER MINING—TWIN SPRINGS.

Figure 4.3. Mining was an important part of Idaho history particularly in northern Idaho (Silver Valley), central Idaho (Elk City), and the Boise Basin. Placer mining, Twin Springs, Idaho (published 1901). Photograph obtained from Library of Congress, Prints and Photographs Division, Horace C. Myers, [reproduction number: LC-DIG-ppmsca-17299].

Figure 4.4. Sheep grazing in central Oregon, 1936. Photograph obtained from Library of Congress, Prints and Photographs Division, Arthur Rothstein, artist [reproduction number: LC-DIG-ppmsc-04821].

Adverse grazing effects were not evenly distributed across the landscape. Livestock driveways and bedding areas and the area around water sources are generally more likely to be severely degraded even today. Because of livestock preference, some waterways, basin meadows, and ridge tops have been used as stock driveways and bedding grounds every season for decades (fig. 4.4), accelerating erosion and shifts in plant communities in as little as 20 years (Griffiths 1902).

Animal numbers peaked on the National Forest System lands in 1919 at approximately 10.8 million animal unit months (AUMs). By the 1910s, the Forest Service began to regulate grazing (Jardine and Anderson 1919), although the success of regulation varied (Fedkiw 1998). The primary emphasis was on selecting the appropriate species for the range type and topography, reseeding degraded rangelands, and reducing livestock numbers (Jardine and Anderson 1919). Grazing on other federal lands became fully regulated following passage of the Taylor Grazing Act in 1935, although the number of animals was already in decline. After World War II, grazing management emphasis shifted towards improving range conditions and less on reducing animal numbers (Fedkiw 1998). The emphasis of cattle producers also shifted from hides to meat due to a growing demand for beef. Since 1970, however, cattle numbers began to decline again due to decreased demand for beef, increasing environmental regulation as range conditions failed to improve, and drought. Grazing by sheep has declined more or less steadily since the end of World War II as demand for mutton declined and synthetic fabrics replaced wool (Fedkiw 1998).

The introduction and spread of invasive species is often associated with livestock grazing. Invasive annual grasses have proven especially problematic in semi-arid landscapes, although less so in forests. Cheatgrass was initially introduced as a contaminant in imported wheat seed and initially spread along railroads from contaminated straw and wheat (Reid and others 2008). The exact role of livestock in spreading cheatgrass is less certain, although the dominant grazing practices prior to the early 1900s created plenty of growing space (Cottam and Evans 1945; Daubenmire 1940; Griffiths 1902). Cheatgrass also spread rapidly from abandoned farms in the 1920s and ’30s in combination with severe drought (Piemeisel 1938). Other rarely acknowledged factors in the spread of cheatgrass and other invasive plants include wildlife and recreational users.

The introduction of tree diseases has also significantly altered tree species compositions and probable post-fire responses of various types of dry mixed conifer forests. The accidental introduction of white pine blister rust in the early 1900s provides a case example. This disease dramatically reduced the numbers of western white pine in the northern Rocky Mountains and sugar pine in the southern Cascades (Kinloch 2003) (fig. 4.5). Control attempts included eradication of the alternate hosts, gooseberry (*Ribes* species); the other option was to create large clearcuts (hundreds of acres) and burn them, this was followed by pulling the gooseberry bushes and planting western white pine in the middle of the clearcut (Kinloch 2003). This practice led to the incorporation of clearcutting and burning as a dominant method for forest management. After these initial efforts at eradication, the disease was not eradicated; thus the philosophy that all western white pine would be eventually killed by blister rust. A massive salvage effort ensued, further decreasing the abundance of western white pine. Recently, the introduction of Sudden Oak Death has the potential to greatly alter species compositions in the dry mixed conifer forests of southern Oregon and northern California by impacting Tanoak.

Timber harvesting policies and practices on federal lands have been a primary factor in shaping the current condition of the dry mixed conifer forests. Fedkiw (1998) provides a detailed history of management and policy related to the National Forest System lands, much of which also applies to other federal forest lands.

Prior to 1940, the national harvest levels were less than 1 billion board feet annually, largely to meet local needs. Most harvesting used selection-cutting methods, except in

Figure 4.5. Introduction of blister rust in the early part of last century led to a variety of attempts to eradicate the alternate host the gooseberry. The disease enters through a needle and then progresses to the stem where the tree is killed through girdling. This is a blister rust canker. Photo by Ed F. Wicker, U.S. Department of Agriculture, Forest Service.

the Pacific Northwest Douglas-fir region, where clearcutting was the norm and in areas where railroad logging was used (fig. 4.6). Following World War II, decreased supply of private timber in combination with increased U.S. population, economic activity, and transportation networks fueled a dramatic increase in the demand for federal timber. Harvest levels increased from 1950 to 1970, temporarily peaking in 1969 at 12.6 billion board feet, and fluctuated around 11.0 billion board feet per year until the 1990s. Clearcutting and other even-aged management techniques became dominant along with a variety of other practices intended to protect and enhance forest production, such as reforestation, sometimes favoring single species, the use of herbicides to control competing vegetation, intermediate treatments, and attempts to control insects, disease and fire. Harvesting was concentrated on old growth stands and on the most commercially important species, such as ponderosa pine, western larch, and Douglas-fir.

Beginning in the 1960s and accelerating through the 1970s, ’80s, and ’90s, controversy over these intensive forest management practices increased, resulting in the passage of numerous laws intended to increase the timber supply from federal lands and manage the environmental impacts of timber management practices. By 1994, timber harvest levels on federal lands had dropped to a level last seen in the mid-1940s and has remained at that level since. The decline was largely driven by concerns over the impacts of intensive forest management on fish and wildlife habitat with the passage of the Endangered Species Act.

Fire policy was probably the other major factor shaping the dry mixed conifer forest. Initially, many settlers continued burning the landscape, using many of the same practices as the American Indians and often for the same purposes, as well as for clearing land for farming, grazing, or prospecting (Pyne 1982, 1984). Abandoned campfires remain a persistent problem even today. However, some of the largest and most lethal fires arose from primitive logging practices in combination with drought, lightning, sparks from railroads, and human carelessness. Fires were also started accidentally and as retaliation for real and perceived wrongs and to create work.

The perceived need for rapid suppression of all wildfires was reinforced by wildfires that burned in northern Idaho, eastern Washington, and western Montana in August of 1910. These fires burned millions of forested acres, towns, and caused considerable loss of life (Egan 2009; Pyne 2001) (fig. 4.7). Public perception of these events as destructive cemented the mission of the newly formed Forest Service to protect the valuable forestlands of the United States from fire and other damaging disturbances (Steen 1976). Systematic fire protection developed through the 1910s and '20s as a result of the 1910 fire (fig. 4.7). The drought of the 1920s and early 1930s and subsequent large fires resulted in creation of the so-called 10 a.m. policy, requiring that all fires be controlled by 10 a.m. the following day (Pyne 1982, 1984). Smoke-jumping as a primary attack method began during World War II (Pyne 1984). The availability of surplus military equipment following the end of World War II, in combination with increased road building, greatly enhanced firefighting capability through increased use of mechanized equipment and aerial attack tactics (Pyne 1984). The result was a large reduction in the number of acres burned in western forests, although in recent years, some have argued that a change in climate to cooler, wetter conditions during this same period was also a significant factor. By the early 1970s, however, forest managers were noticing an increase in the accumulation of forest fuels. This factor, in conjunction with passage of the Wilderness Act in 1964 and increasing understanding of forest ecology, led the National Park Service and Forest Service to begin experimenting with the use of lightning-caused fires in large back country and wilderness areas (Pyne 1982, 1984). Widespread use of prescribed fire to eliminate logging slash and improve wildlife habitat also began in the western United States (Fedkiw 1998; Pyne 1984). This period also saw the development of greater coordination between the federal land management agencies and states, leading to standardization of equipment, crew configurations, fire training and qualifications, and so forth (Pyne 1984).

Figure 4.6. Preferential harvest of fire resistant species such as western larch and ponderosa pine favored the growth of the remaining shade tolerant species such as grand fir and white fir. In addition, with the advent of fire suppression, trees such as grand fir, Douglas-fir, and white fir regenerated underneath remaining stands of western larch and ponderosa pine. Photograph obtained from Library of Congress, Prints and Photographs Division, Photographs of five Idaho loggers taken by Dorothea Lange, 1939 [reproduction number:LC-USF346-BN-021622], and steam logging by T. M. Kelso, 1902 [reproduction number: LC-USZ62-97669].

Figure 4.7. Photograph taken September 1910, after the 1910 wildfire, the Pulaski Tunnel where fire fighters took refuge and five perished. The tunnel is 60 ft long, Near Wallace, Idaho. U.S. Department of Agriculture, Forest Service photograph courtesy of the Forest History Society, Durham, N.C. FHS2658.

The use of lightning-caused fires to meet land management objectives was called into question following a series of large and expensive wildfires in and around Yellowstone National Park in 1988. Although the basic policy was determined to be sound, additional implementation procedures were developed. At this time, each federal agency still had separate fire management policies. That changed following the deaths of 14 firefighters in the South Canyon Fire in 1994. In 1995, a unified federal fire policy was created. Implementation of this policy remained irregular until the events of the 2000 fire season, which saw large escaped fires in the Southwest and fires approaching the scale of 1910 in the northern Rockies.

The 2000 fire season resulted in two significant changes in federal fire policy. First, aspects of the federal fire policy were strengthened and Congress directed the federal agencies to standardize all aspects of wildfire response across the five federal agencies. Second, the National Fire Plan was created to respond to the growing threats of large, costly, and life-threatening wildfires arising from changes in forest conditions, the growing number of homes constructed where communities met wildlands (the wildland-urban interface (WUI)), and the changing climate.

Consequences of Past Management for Forests and Fuels

Tree Species Shifts and Insects and Disease

The combination of harvesting, overgrazing, fire suppression and exclusion, and access through roads and railroads all contributed to the composition and structure of the forests we see today (Harvey and others 2000). For example, abundant fir in the understory creates nutrient-rich ladder fuels that facilitate crown-fire initiation, increasing the likelihood of nutrient loss (van Wagner 1977; Minore 1979; Harvey and others 1999) (fig. 4.8). The risk of nutrient loss is greater on infertile sites because dense stands of late-seral species tend to contain more nutrients than the historical stands dominated by widely spaced, early-seral species (Minore 1979; Harvey and others 1999) (fig. 4.8).

Historically, native insects and disease (for example, pine beetle, root disease, and mistletoe) infected and killed very old or stressed individuals, a process that tended to diversify vegetation communities (Hessburg and others 1994). However, in present-day forests, changes in vegetation coupled with subtle changes in climate cycles have facilitated development of unprecedented epidemic levels of insects and diseases in many locales. These disturbance agents have often been encouraged by weather events such as ice storms, windstorms, and periodic droughts. In addition, settlers moving into the western United States introduced exotic plant and animal species, often displacing native species. Non-native insects and diseases found no natural checks, enabling them to invade western forest ecosystems unimpeded.

Figure 4.8. Fire suppression promoted the regeneration of shade tolerant species. Photograph on left taken at Boise Basin Experimental Forest, near Idaho City, Idaho. Photo by Jonathan Sandquist, USFS. Photo on the right is the Crane Mountain Roadless area, Oregon, by Andris Eglitis, U.S. Department of Agriculture, Forest Service.

Today, ponderosa pine continues to be susceptible to the western pine beetle. In addition, mountain pine beetle frequently kills ponderosa pine on Douglas-fir and grand fir/white fir LANDFIRE BpS (see chapter 2). The pine engraver beetle is more abundant and destructive today with some of the severest outbreaks occurring in low-elevation ponderosa pine LANDFIRE BpS (see chapter 2). (Hessburg and others 1994).

Within the Inland Northwest, ponderosa pine is being succeeded by Douglas-fir and grand fir (Jain and Graham 2005; Gruell and others 1982; Keane and others 2002; Smith and Arno 1999). The amount of mid-seral (for example, Douglas-fir) vegetation has increased by nearly 3.2 million ha (8 million acres) and the amount of single-storied, mature vegetation (for example, ponderosa pine) has decreased by over 1.6 million ha (4 million acres) (Hann and others 1997). The accumulation of fire-intolerant vegetation, dense forest canopies, with large areas (hundreds of acres) with continuous compositions and structures has resulted in forests favoring crown fires rather than the historical mixed severity fires (Halofsky and others 2011; Hessburg and Agee 2003; Perry and others 2011). In many areas, these changes have shortened successional timeframes. For example, under historical, frequent fire regimes, ponderosa pine, western larch, and sugar pine were normally succeeded by Douglas-fir or true firs in 300 to 400 years without disturbance; however, these species have succeeded ponderosa pine in less than 50 years in many locations (Hann and others 1997; Harvey and others 1999; Smith and Arno 1999). In addition, stands of Douglas-fir, grand fir, and white fir are susceptible to both defoliators and root diseases, thus perpetuating disease and insect infestations.

Soil Impacts

In addition to noticeable changes in plant composition and structure, the soils (surface and mineral) in many settings have also changed considerably during the last century (fig. 4.9). The regeneration and growth of grand fir/white fir and Douglas-fir in the dry forests has subsequently led to the accumulation of both above- and below-ground biomass and associated nutrients close to the soil surface (Harvey and others 1986).

Figure 4.9. Often the changes in overstory composition and structure are emphasized; however, soils have also changed. Photograph on left taken by 1874 Custer Expedition. Notice the rock outcrop. On the right side is the same location, photograph taken 128 years later; the rock is almost buried by organic matter and needles. Photo by Paul Horsted. Published in Grafe and Horsted (1992).

Today, even low-intensity surface fires can consume the surface organic layers, killing tree cambiums and/or fine roots, volatilizing nutrients, killing trees, and increasing soil erosion potential (DeBano 1991; Hood 2010; Hungerford and others 1991; Ryan and Amman 1996; Robichaud and others 2000) (fig. 4.10).

The accumulation of organic materials on the soil surface and the frequent changes in their composition (for example, ponderosa pine litter to true fir litter) can also alter fine root and ectomycorrhizae (a root fungus that has a symbiotic relationship with plants that helps with nutrient and water uptake) habitat and water-holding properties (Harvey and others 1999; Harvey and others 2000). Fine root and ectomycorrhizal activity in historical fire dependent sites occurred deeper in the mineral soil of forests dominated

Figure 4.10. Deep duff layers have increased around the bole of the tree (top photograph) in some places within the dry mixed conifer forests. In highly productive places, fine roots can migrate into the deep duff. Thus when fire is reintroduced, there is a risk of causing fine root and/or bole injury to the tree leading to potential delayed mortality (Hood 2010). Photo by Theresa Jain, U. S. Department of Agriculture, Forest Service.

by ponderosa pine; thus, they were protected from being damaged during fires (Harvey and others 1986). On true fir-dominated sites and where fire has not occurred for many decades, fine roots and ectomycorrhizae have migrated into shallow organic horizons. Depending on the aspect, dry mixed conifer areas of Idaho, Oregon, and Washington can be susceptible to root and ectomycorrhizae migration (Hood 2010) (fig. 4.10).

In general, historical dry mixed conifer forests were long-lived and resilient. They were also likely well matched to soil resources, relatively resistant to detrimental fire effects, well adapted to wide ranges of site and short-term climate variation, and subject to modest (largely beneficial) insect and pathogen mortality. In contrast, forests that were dominated by ponderosa pine and are now dominated by Douglas-fir, grand fir or white fir are probably not well matched to soil resources and are also not likely resistant to the wide range of site and climate variation found within the dry forests. In turn, they are often subject to high insect and pathogen mortality and cannot be considered either long-lived or stable (Harvey and others 1999).

Forests in our synthesis area offer many amenities that are valued by people. Today, the forests provide livelihoods (logging and mining), places to live, and recreational activities such as berry picking, hunting, hiking, biking, fishing, and camping. Federally administered lands dominate states like Idaho, promoting the value of public lands for recreation and other values. Consequently, the attraction of these rural forested settings has encouraged the expansion of the WUI. As the WUI has expanded, sociocultural factors have become increasingly important in forest management and fuel treatment programs. Surveys of the general American public show support for the environment and the value of forests; however, there is variability in people's attitudes, beliefs, and values based on where they live and their livelihood. (Attitudes are peoples' evaluation of something favorable or unfavorable. Beliefs reflect what people think is true about something. Values reflect the things people hold dear to them) (USDA 1996, page 37). The Columbia River Basin Assessment (Quigley and others 1997a) conducted a comprehensive survey of residents in an area roughly corresponding with the synthesis area. The authors found that support for endangered species laws and regulations remains strong but the public is concerned with the balance between species protection and costs to society. This concern is particularly strong among rural residents. Disturbance events such as fire, insects, and disease have negative connotations to many people. Although people understand that these occur naturally, they consider the results to be "a waste of good resources." An important value held by survey respondents is the "sense of place," which is how people define ecosystems and specific locations in the landscape based on their experiences, meanings, and images. The assessment also noted that the public prefers to work with Federal agencies and others having management authority rather than relying on legislation or court cases to achieve mutually desirable outcomes. Humans have had a profound effect on natural resources and their attitudes, beliefs, and values will continue to play a major role in fuel treatment implementation.

Conclusion

Although many forests of the Northwest, including the dry mixed conifer forests, have experienced an array of repeated disturbances over time, they have shown remarkable resilience. These forests still have many elements that maintain their resilience and afford numerous opportunities for improved management. We have the opportunity to decide how we will influence them going into the future. We also have to recognize our limitations and incorporate those into discussions and management decisions.

It is important to recognize that humans are part of these forests, and we are going to continue to influence how they function. Although the public recognizes the value of fire, many are still apprehensive. Therefore, issues such as smoke impacts will most likely always prevent a broad application of fire. Also, dry mixed conifer forests are located within or close to the rapidly expanding wildland urban interface. Fires will continue to be suppressed, depending on the time of the year, location, and other factors. Therefore, the full re-introduction of fire across the entire range of the dry mixed conifer forests will most likely not be achieved.

The seed sources of resilient species such as ponderosa pine, western larch, sugar pine, and western white pine may no longer exist on some sites. If they were to burn in a wildfire, the species currently present will most likely recapture the site creating a different successional cycle than what historically occurred.

Insects, disease, and the effects from physical disturbances such as ice, snow, and wind will continue to occur and with the uncertain influences of a changing climate, they may potentially play a major role in promoting mortality and altering the pattern and distribution of fuels. Some areas that are disease or insect infested are not accessible, and there is considerable sensitivity to increasing road networks in federally administered forests. Other management alternatives are economically prohibitive. Thus, this future fuel matrix and continued tree mortality will also be a part of these forests.

Given these realities, how do we manage the dry mixed conifer forests into the future? Humans most likely will take a major role in the shape of these forests over the next several centuries. Fuels management is going to continue and consideration of the challenges and opportunities may promote discussion about the consequences of our actions and decisions.

The objective of this chapter (and Chapter 3) was to recognize that: (1) given all of the disturbances these forest have experienced, these forests still show resilience and can be managed to meet a range of ecological, economic, and social needs; (2) changes have occurred and management aimed at mimicking the past may not be possible; and (3) disturbance, not just fire, is what maintained these forests and will continue to function in these forests into the future. Accepting these realities and respecting the role disturbance played and continues to play in influencing how these forests function will allow for improved forest management moving forward.

Further Reading

Belsky, Joy A.; Blumenthal, Dana M. 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the Interior West. Conservation Biology. 11(2): 315-327. (Provides a comprehensive review of the effects of cattle and sheep grazing on forest structure and processes, including the effects on fire regimes.)

Fedkiw, John. 1998. Managing multiple uses on National Forests, 1905-1995: a 90-year learning experience and it isn't finished yet, [Online]. Available: http://www.foresthistory.org/ASPNET/Publications/multiple_use/contents.htm [2012, May]. (Provides a detailed summary of the management history of the National Forests.)

Keane, Robert E.; Ryan, Kevin C.; Veblen, Tom T.; Allen, Craig D.; Logan, Jesse; Hawkes, Brad. 2002. Cascading effects of fire exclusion in the Rocky Mountain ecosystems: a literature review. Gen. Tech. Rep. RMRS-GTR-91. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p. (Provides a literature review of the factors that led to changes in forest structure and composition; with emphasis on the effects of fire suppression and exclusion.)

Williams, Gerald W. 2001. References on the American Indian use of fire in ecosystems, [Online]. Available: http://www.wildlandfire.com/docs/biblio_indianfire.htm [2012, June]._Williams (2001). (Provides a short summary of the influence of American Indian burning.)

Chapter 5

Inventory Modeling of Current Fire Hazard Conditions

Chapter Rationale

The following questions motivated inclusion of this chapter:
What are the current conditions of the dry mixed conifer forests?
What is the status concerning fire hazard?

We address these questions via an analysis of forest inventory plot data using a fire hazard model.

Introduction

This chapter and appendix A summarize what we know about current conditions in dry mixed conifer forests, drawing on analysis of FIA (Forest Inventory and Analysis National Program) inventory data and applying the FFE-FVS (Fire and Fuels Extension of the Forest Vegetation Simulator) (Reinhardt and Crookston 2003) model. Relying on the systematic random sample of FIA data ensures a statistically robust representation of the entire forested landscape—not just the stands that merit or appear manageable through fuel treatment today. We summarize the current extent of forest fire hazard from multiple perspectives by sub-region and broad forest type groups to facilitate local application of the information in this chapter and appendix A.

Analytic Approach

A total of 5,174 FIA plots in Oregon, Washington, Idaho, Montana, Utah, and extreme northern California[1] were selected for this analysis via overlay on a GIS grid coverage representing dry mixed conifer types derived from the LANDFIRE vegetation layers (see chapter 2 for details). These plots, installed between 2001 and 2009 and representing nearly 37.7 million acres of forest land, were processed using FFE-FVS to summarize stand attributes related to fire hazard. Each accessible forest land (Bechtold and Patterson 2005) condition[2], which can be thought of as a plot or partial plot that represents or “stands in for” thousands of acres in the forested landscape, was processed using the FVS variant appropriate to its location. However, for simplicity, we report model results

[1]Due to the late initiation of annual inventory in Nevada and Wyoming, there were no annual inventory, dry mixed conifer plots in the parts of those states included in our study area, so this analysis does not apply to those states.

[2]Because FIA uses a mapped plot design in which plots are subdivided into “conditions” when there are sharp discontinuities within the forested parts of a plot (for example, in size class, forest type, stand density, land owner group, and reserve status) or when an otherwise forested plot includes non-forested area, the basic unit of analysis is condition, not plot.

by study area sub-regions, created as aggregations of FVS variant regions: Northern California and Klamath, Pacific Northwest Interior, Northern and Central Rocky Mountains, and Utah, as shown in fig. 5.1 and table 5.1. Results are summarized using FIA plot expansion factors to represent acres and/or fractions of the forested landscape in each sub-region and forest type group that are deemed hazardous by various criteria. For this analysis, we grouped forest types into six forest type groups: Douglas-fir and True Fir, Pine and Western Larch, Quaking Aspen (includes birch), Cedar (western redcedar), Non-stocked, and a grab bag of everything else that we call Other Species[3].

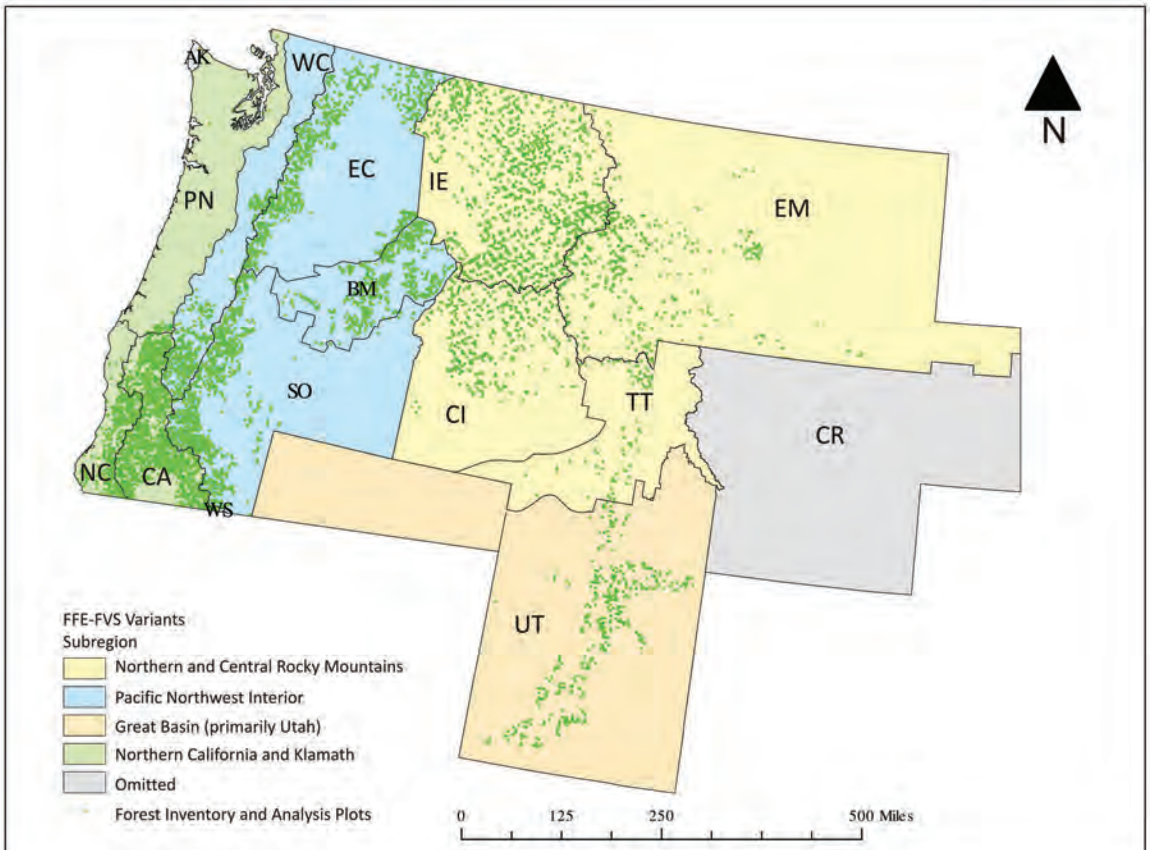


Figure 5.1. Map of Forest Vegetation Simulator (FVS) variant applicability for the variants used in analysis of current condition and to model treatment alternatives in the dry mixed conifer fuel synthesis area. Two-letter variant code translations are as follows: PN—Pacific Northwest Coast, NC – Klamath Mountains, CA – Inland California and Southern Cascades, WC – Westside Cascades, EC – East Cascades, BM – Blue Mountains, SO – Southern Oregon and Northeast California, IE – Northern Idaho (Inland Empire), CI – Central Idaho, TT – Tetons, EM – Eastern Montana, UT – Utah, CR – Central Rockies (note: not used in this analysis due to lack of annual inventory data).

[3]Other Species includes forests belonging to one of 45 FIA forest types: Bigleaf maple, Blue oak, Blue spruce, California black oak, California laurel, California mixed conifer, California white oak, Canyon live oak, Cercocarpus woodland, Cottonwood, Cottonwood / willow, Deciduous oak woodland, Engelmann spruce, Engelmann spruce / subalpine fir, Foxtail pine / bristlecone pine, Giant chinkapin, Gray pine, Incense-cedar, Intermountain maple woodland, Jeffrey pine, Juniper woodland, Knobcone pine, Limber pine, Lodgepole pine, Misc. western softwoods, Mountain hemlock, Noble fir, Oregon white oak, Other hardwoods, Pacific madrone, Pacific silver fir, Pinyon / juniper woodland, Port-Orford-cedar, Red alder, Red fir, Redwood, Rocky Mountain juniper, Sitka spruce, Subalpine fir, Sugar pine, Tanoak, Western hemlock, Western juniper, White fir, or Whitebark pine.

Table 5.1. Area of all forest and of unreserved forest and number of conditions (full or partial FIA plots) contained in each FVS (Forest Vegetation Simulator) variant applicability area and study area subregion. All forests include areas such as wilderness, natural areas and parks where harvest is prohibited. Unreserved forest is forest land where harvest is not prohibited by law.

FVS variant	All forest area (1000 ac)	Unreserved forest	
		Area (1000 ac)	Conditions
Northern California and Klamath			
Inland California and Southern Cascades (CA)	5,902	5,060	930
Klamath Mountains (NC)	1,962	1,666	284
Pacific Northwest Coast (PN)	117	117	25
Total	7,981	6,843	1,239
Pacific Northwest Interior			
Blue Mountains (BM)	2,690	2,136	394
Eastern Cascades (EC)	4,404	4,063	645
South Central Oregon and Southeast California (SO)	4,293	4,058	737
Westside Cascades (WC)	2,023	1,879	350
Total	13,411	12,136	2,126
Northern and Central Rocky Mountains			
Central Idaho (CI)	2,942	2,254	260
Eastern Montana (EM)	2,609	2,389	309
Inland Empire (IE)	8,221	7,158	915
Teton (TT)	620	579	64
Total	14,392	12,381	1,548
Utah			
Utah (UT)	1,963	1,787	333
Total	1,963	1,787	333
Omitted			
Southeast Alaska and Coastal British Columbia (AK)	5	5	3
Western Sierra Nevada (WS)	20	20	3
Central Rockies (CR)	11	1	1
Total	37	27	7
Grand total	37,784	33,173	5,253

FFE requires a surface fuel model (see Anderson, 1982), or composite (weighted combination of) surface fuel models, and fuel moisture data to compute some indices. We relied on FFE's variant-specific, default surface fuel model selections (as informed by the plot tree list data) and default values for fuel moisture under severe weather conditions. For example, for the Inland Empire variant, severe weather fuel moistures for 1-hour, 10-hour, 100-hour, 1000-hour fuels (which correspond to woody debris diameter classes of 0-¼, ¼-1, 1-3 and >3 inches), duff , live woody, and live herb were, respectively, 4, 4, 5, 10, 15, 70, 70 percent; 20 ft wind speed above the canopy was 20 mph; and temperature was 70 °F. FFE-FVS uses the tree list, information on surface fuels, and the fuel moisture assumptions to compute various fire hazard, behavior and effects indices. We evaluated these indices for their utility in assessing current hazard and selected four to fully analyze, track and report. Probability of torching in severe weather conditions (ptorch) and torching index (TI), the wind speed at which crown fire initiation would be expected, both relate to torching—the transition of a surface fire, via ladder fuels, into the crowns of some or all of the trees, making the fire partly or fully stand-replacing. We rely on surface flame length (SFL) as a proxy for both fire intensity and fire suppression effectiveness (e.g., high flames may preclude direct attack). We use mortality volume, after transforming it into a percent of pre-fire, live-tree volume (MortVolPct), as an indicator of economic and resource loss, as well as the viability of the residual stand, and because of its implications for reversals of carbon storage. Acres were deemed hazardous for purposes of this overview of current conditions if ptorch > 20 percent, TI < 20 mph, SFL >4 ft, or MortVolPct > 30 percent. Note that this conceptualization of hazard is only one of many potentially sensible choices. Depending, for example, on stand management objectives, whether or not fire suppression would be attempted, and whether or not timber management plays a role, a manager might choose other thresholds for these criteria, or perhaps a different set of criteria altogether. We also considered and report a composite hazard score calculated as the number of these four criteria by which an acre qualifies as hazardous, producing a hazard score between 0 and 4.

Findings

Of the 37.7 million acres of dry mixed conifer forest represented by the inventory database, 21, 36, 38, and 5 percent of these acres are within the Northern California and Klamath, Pacific Northwest Interior, Northern and Central Rocky Mountains, and Utah sub-regions, respectively (table 5.2). Across all forest type groups, reserved forested lands (in other words, in state and national parks, and statutorily designated wilderness) account for 8.5 to 14.3 percent of forested area, depending on sub-region. Considering all sub-regions together, for both reserved and unreserved forests, there are more than six times as many acres rated hazardous by one or more criteria as there are acres rated resilient by all criteria, though there is considerable variation among sub-regions—for example, the ratios of hazardous to resilient acres is 4.8 and 15.2 in the northern and central Rocky Mountains and Utah, respectively. Because this synthesis focuses on forested acres where fuel treatments might conceivably be contemplated, the rest of this chapter and the chapter addressing fuel treatment feasibility (Chapter 11) consider only forested conditions on unreserved lands, and exclude forest land that is not currently stocked with trees.

Douglas-fir, True Fir, Pine and Western Larch Types Dominate

Focusing on unreserved forests, we find that about half the area represented by conditions selected via LANDFIRE BpS overlay are attributed on the ground as forest types we typically think of as dry mixed conifer types, with the Douglas-fir and True Fir type group covering the greatest share of this, and the Pine and Western Larch type group covering most of the rest (table 5.3a).

Steep Slopes are Common in Some Sub-Regions

Considering that slope is an important determinant of treatment difficulty and cost, we summarized unreserved forest area by sub-region and slope class, and found considerable regional variation: the proportion of area in steep slopes ranges from 0.2 in the Pacific Northwest Interior to 0.5 in Northern California and Klamath (table 5.3b).

Table 5.2. Area of forest land and percent of forest land by reserve status and hazard status, by FVS subregion and forest type groups, as of 2009. Percent of acres rated resilient versus hazardous by forest class. Those that were rated hazardous had a hazard score of > 0. Reserved forests are those that are in state and national parks and wilderness. Unreserved are forests that are accessible for fuel treatments.

		Percent of area in forest class			
		Unreserved		Reserved	
Forest type groups	Area (acres)	Resilient	Hazardous	Resilient	Hazardous
Northern California and Klamath					
Douglas-fir and true fir	1,179,300	18.9	77.4	0.6	3.1
Pine and Larch	346,829	21.7	68.7	0.0	9.6
Aspen	NA	NA	NA	NA	NA
Cedar	7,173	0.0	100.0	0.0	0.0
Other Species	6,298,022	10.2	73.7	2.3	13.8
Nonstocked	149,670	0.0	69.4	0.0	30.6
All forest	7,980,993	11.8	74.0	1.9	12.4
Pacific Northwest Interior					
Douglas-fir and true fir	4,774,498	9.5	79.5	0.7	10.2
Pine and Larch	3,058,771	11.9	83.2	0.6	4.3
Aspen	36,972	0.0	100.0	0.0	0.0
Cedar	37,368	0.0	82.9	0.0	17.1
Other Species	5,129,783	2.7	86.6	0.8	10.0
Nonstocked	373,815	0.9	87.2	0.0	11.9
All forest	13,411,208	7.2	83.3	0.7	8.8
North and Central Rocky Mountains					
Douglas-fir and true fir	6,179,017	21.8	67.0	1.7	9.5
Pine and Larch	2,058,917	26.5	66.5	1.9	5.1
Aspen	340,395	17.1	71.1	2.6	9.2
Cedar	269,370	2.0	90.8	0.0	7.2
Other Species	4,777,662	1.1	81.1	0.5	17.3
Nonstocked	766,443	15.5	49.7	1.4	33.4
All forest	14,391,805	14.8	71.2	1.3	12.7
Utah					
Douglas-fir and true fir	311,145	23.9	65.1	6.3	4.8
Pine and Larch	50,493	37.2	47.5	12.2	3.1
Aspen	772,677	1.6	94.5	0.0	3.9
Cedar	NA	NA	NA	NA	NA
Other Species	808,244	0.6	86.6	0.0	12.8
Nonstocked	20,204	0.0	100.0	0.0	0.0
All forest	1,962,762	5.6	85.4	1.3	7.6

Table 5.3. Acres by forest type group for unreserved (land outside of State and Federal parks and wilderness areas). a) Unreserved forest area by forest type group; b) Unreserved forest area by subregion and slope class.

a)

Forest type groups	Area (acres)
Douglas-fir and true fir	11,153,051
Pine and Larch	5,178,247
Aspen	1,079,628
Cedar	288,211
Other Species*	14,493,511
Nonstocked	953,187
Total	33,145,835

b)

Subregion	Forest area acres	Percent of forest in subregion	
		Steep (>40%)	Gentle (<= 40%)
Northern California and Klamath	12,380,552	41	59
PNW Interior	12,135,708	20	80
North and Central Rockies	1,787,021	33	67
Utah	6,842,555	50	50
Total Study Area	33,145,835		

* "Other" consists of forests belonging to one of 45 FIA forest types: bigleaf maple, blue oak, blue spruce, California black oak, California laurel, California mixed conifer, California white oak, canyon live oak, cercocarpus woodland, cottonwood, cottonwood / willow, deciduous oak woodland, engelmann spruce, engelmann spruce / subalpine fir, foxtail pine / bristlecone pine, giant chinkapin, gray pine, incense-cedar, intermountain maple woodland, jeffrey pine, juniper woodland, knobcone pine, limber pine, lodgepole pine, misc. western softwoods, mountain hemlock, noble fir, Oregon white oak, other hardwoods, Pacific madrone, Pacific silver fir, pinyon / juniper woodland, Port-Orford-cedar, red alder, red fir, redwood, Rocky Mountain juniper, Sitka spruce, subalpine fir, sugar pine, tanoak, western hemlock, western juniper, white fir, and whitebark pine.

Hazard Dimensions are Highly Varied

Our four indicators of hazard are only weakly correlated. For example, in every sub-region, most of the acres fall into a middle ground between hazardous by every indicator and resilient (not hazardous) by every indicator (table 5.4). In every sub-region, the most common hazard status is hazardous by all four indicators ("yes" to all four indicators), and there are a considerable number of areas rated resilient by the torching index criterion but hazardous by one or more of the other criteria. The amount of area rated resilient on all counts amounts to as little as 6 percent of forested acres in Utah, to a maximum of 17 percent in the northern and central Rocky Mountains. These statistics would certainly shift with different choices of hazard thresholds, but a key message is that hazard rating does depend on the criterion considered.

Combining the criteria into a hazard score (the count of criteria by which an acre qualifies as hazardous) is one approach to considering relative hazard in a multi-criteria context. Conceivably, an acre that is hazardous with respect to crown fire likelihood, predicted mortality losses, and likely effectiveness of fire suppression (as indicated by a hazard score of 3 or 4) would be a higher priority for fuels management than one with hazard in only one dimension. The distribution of acres by hazard score appears to differ among sub-regions, with Utah having the fewest resilient acres as a percent of the total, and the northern and central Rocky Mountains the most (fig. 5.2).

Table 5.4. Area and percent of unreserved forested land by subregion, rated hazardous by different combinations of hazard concepts: Ptorch >20%, TI <20, SFL >4 ft and VolMortPCT >30.

Ptorch	TI	SFH	VolMortPct	Area (ac)	Percent
		Northern California and Klamath			
Yes	Yes	Yes	Yes	1,972,023	28.8
Yes	Yes	Yes	No	13,575	0.2
Yes	Yes	No	Yes	107,339	1.6
Yes	Yes	No	No	13,162	0.2
Yes	No	Yes	Yes	1,122,019	16.4
Yes	No	Yes	No	400,759	5.9
Yes	No	No	Yes	497,425	7.3
Yes	No	No	No	413,563	6.0
No	Yes	Yes	Yes	63,645	0.9
No	Yes	No	Yes	8,669	0.1
No	No	Yes	Yes	148,415	2.2
No	No	Yes	No	397,125	5.8
No	No	No	Yes	746,644	10.9
No	No	No	No	938,193	13.7
				6,842,555	**100.0**
		Pacific Northwest			
Yes	Yes	Yes	Yes	4,282,413	35.3
Yes	Yes	Yes	No	39,844	0.3
Yes	Yes	No	Yes	499,963	4.1
Yes	Yes	No	No	26,032	0.2
Yes	No	Yes	Yes	1,488,994	12.3
Yes	No	No	Yes	980,810	8.1
Yes	No	Yes	No	649,996	5.4
Yes	No	No	No	575,332	4.7
No	Yes	Yes	Yes	299,469	2.5
No	Yes	Yes	No	44,524	0.4
No	Yes	No	Yes	42,997	0.4
No	No	Yes	Yes	429,786	3.5
No	No	No	Yes	823,979	6.8
No	No	Yes	No	991,111	8.2
No	No	No	No	960,459	7.9
				12,135,708	**100.0**
		Northern and Central Rocky Mountains			
Yes	Yes	Yes	Yes	2,913,820	23.5
Yes	Yes	Yes	No	19,476	0.2
Yes	Yes	No	No	11,535	0.1
Yes	Yes	No	Yes	344,432	2.8
Yes	No	Yes	Yes	1,160,783	9.4
Yes	No	Yes	No	187,433	1.5
Yes	No	No	No	332,713	2.7
Yes	No	No	Yes	1,618,850	13.1
No	Yes	Yes	Yes	120,978	1.0
No	Yes	No	Yes	10,588	0.1
No	No	Yes	Yes	326,987	2.6
No	No	No	Yes	2,719,559	22.0
No	No	Yes	No	486,656	3.9
No	No	No	No	2,126,743	17.2
				12,380,552	**100.0**
		Utah			
Yes	Yes	Yes	Yes	640,066	35.8
Yes	Yes	No	Yes	65,853	3.7
Yes	No	Yes	Yes	395,750	22.1
Yes	No	No	Yes	250,713	14.0
Yes	No	Yes	No	20,620	1.2
Yes	No	No	No	78,186	4.4
No	Yes	Yes	Yes	5,626	0.3
No	No	Yes	Yes	45,061	2.5
No	No	Yes	No	26,568	1.5
No	No	No	Yes	148,189	8.3
No	No	No	No	110,388	6.2
				1,787,021	**100.0**

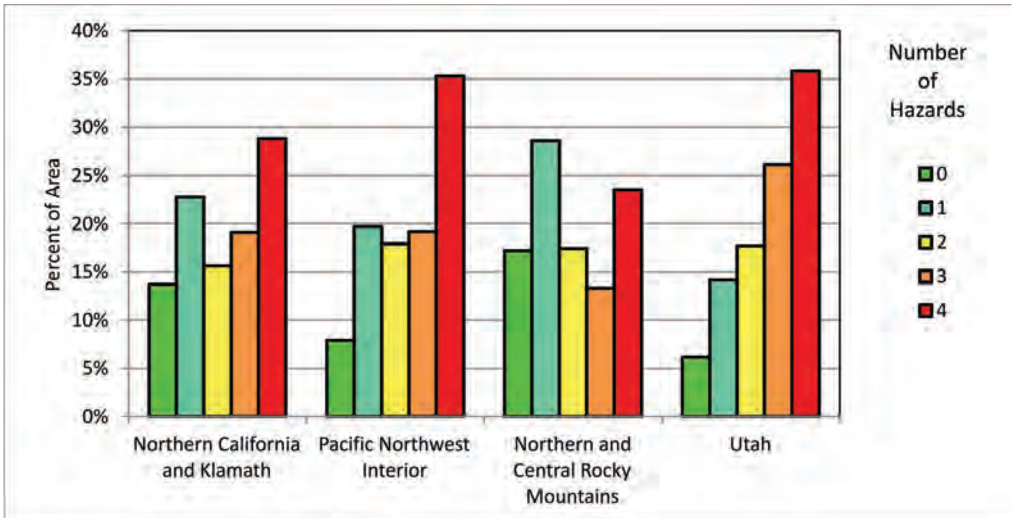


Figure 5.2. The percent of area within each subregion by hazard score (number of ways rated hazardous). There are four hazards that were used to develop the hazard score. The hazard score is based on number of hazards that existed in a given location. The four hazards that were rated are: 1) probability of torching, 2) torching index, 3) surface flame length, and 4) mortality volume as a percent of pre-fire volume. A hazard score of 4 indicates that an acre is subject to all four hazards.

Hazard is Common in All Forest Type Groups

Although wildfire is possible in almost any forest type, we intended that our emphasis in this synthesis be primarily on the Douglas-fir, True Fir, Pine and Western Larch type groups where fuels management is most commonly practiced, on western redcedar in the north and central Rocky Mountains where it occurs in non-negligible abundance, and on aspen/birch in the north and central Rocky Mountains and Utah sub-regions. However, hazard summaries based on the FIA data show that hazard, by our criteria, is high in all forest type groups (fig. 5.3), including Other, though high hazard alone does not necessarily make other forest types a priority for fuels management.

Description of Current Conditions

Histograms[4] showing the distribution of current fire hazard on unreserved forestland in terms of three of the attributes discussed above (TI, MortVolPct, and SFL) and crowning index, canopy cover, trees per acre, basal area, and quadratic mean diameter are published in Appendix A. There is one page of eight histograms (one per attribute) for each combination of sub-region and forest type group, and the pages are grouped by sub-region. In each histogram, the Y-axis represents the proportion of forest area in a sub-region/forest type group. These can be easily translated into acres, if desired, by multiplying the proportions by the area (in acres) printed in the histogram. The mean

[4] Histograms are only plotted for cases where there are at least 10 conditions for a sub-region/forest type group combination. Meaningful histograms can rarely be constructed from less than 10 observations, and in any case, it is inadvisable to attempt inferences from such a small sample.

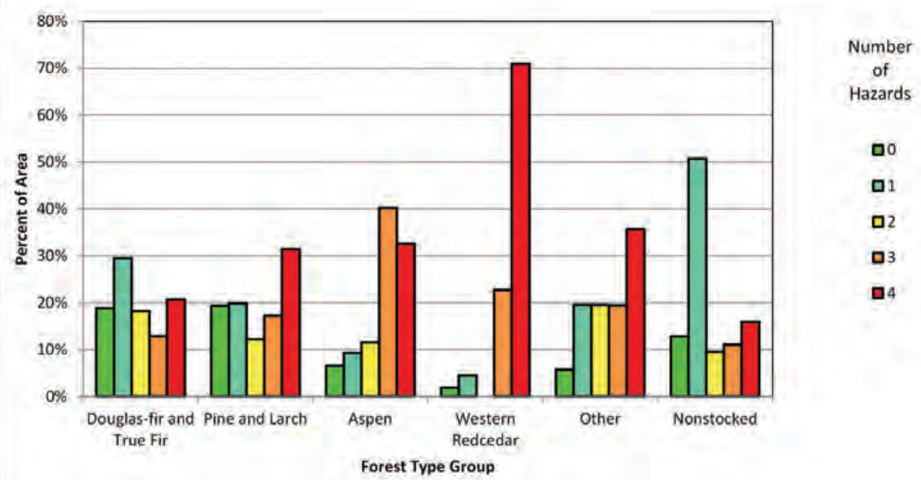


Figure 5.3. Percent of area within each forest type by hazard score (number of ways rated hazardous). There are four hazards that were used to develop the hazard score. The hazard score is based on number of hazards that existed in a given location. The four hazards that were rated are: 1) probability of torching, 2) torching index, 3) surface flame length, and 4) mortality volume as a percent of pre-fire volume. A hazard score of 4 indicates that an acre is subject to all four hazards.

and a roughly calculated[5] sampling error are also printed in the histogram. Sampling errors tend to be smaller as area represented (and the associated sample) increases. The true (population) mean has a 95 percent chance of being contained by the interval constructed as the sample mean ± 2 times the sampling error. In some cases, the X-axis of the histogram is truncated and the last histogram bar on the X-axis also represents all values larger than the x value at that bar; in these cases, the last bar is labeled to also show the maximum value.

What These Data Tell Us

Comparisons among mean values per sub-region/forest type group combination can provide some useful insights (table 5.5). For example, mean ptorch (probability of torching) is greater in Pine and Larch than in Douglas-fir and True Fir and mean ptorch is greater in the Pacific Northwest Interior than for northern California and Klamath or north and central Rocky Mountains and these differences appear to be significant. Mean surface flame length (SFL) is substantially greater in the Pacific Northwest Interior and Northern California and Klamath than in north and central Rocky Mountains for both these type groups, again with indications that the differences are significant. Yet, in neither case do the frequency distributions look like the classical, well-behaved normal distributions—for both these variables, they are either relatively flat, multi-modal (more than one peak), or skewed, and in no case is there a strong, central tendency required for arithmetic means, medians (central value) and modes (most common values) to

[5] These standard errors do not account for the different landscape weights (acre expansion factors) associated with each forested condition.

Table 5.5. Mean and standard errors of selected fire hazard and forest structure attributes for each forest type group, by sub-region.

	Surface flame length		Probability of torching (percent)		Mortality volume (percent)		Crown index		Quadratic mean diameter		Trees per acre		Basal area		Canopy cover	
Forest type group	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Northern California & Klamath																
Douglas-fir and true fir	5.0	0.2	39	3	60	3	37	3	9.7	0.5	430	25	155	7	57	2
Pine/larch	6.6	0.5	49	5	61	5	59	6	10.5	0.8	287	38	104	10	39	3
Other Species	5.3	0.1	53	1	64	1	47	2	9.1	0.2	466	14	142	3	56	1
Pacific Northwest Interior																
Douglas-fir and true fir	5.9	0.1	48	1	65	2	36	1	10.2	0.2	334	12	133	4	50	1
Pine/larch	6.2	0.1	50	2	55	2	61	2	10.4	0.3	215	10	83	2	34	1
Other Species	5.5	0.1	58	1	77	1	46	2	8.1	0.2	441	17	100	3	38	1
Northern and Central Rocky Mountains																
Douglas-fir and true fir	3.3	0.1	30	1	64	1	35	1	8.8	0.2	340	14	100	2	45	1
Pine/larch	4.6	2.0	34	2	49	2	56	3	10.0	0.3	232	16	79	3	33	1
Aspen	5.3	0.6	43	6	59	6	91	12	5.1	0.5	356	5	51	7	34	4
Cedar	8.7	0.4	73	6	86	5	33	3	10.6	1.0	452	73	175	20	62	4
Other Species	4.9	0.1	60	2	81	1	34	1	6.9	0.2	580	24	110	3	43	1
Utah																
Douglas-fir and true fir	2.1	0.3	29	5	83	5	28	3	7.5	0.4	407	42	100	8	44	3
Aspen	5.5	0.2	69	3	78	2	70	7	6.4	0.2	555	36	96	5	54	2
Other Species	5.4	0.3	76	3	82	3	34	5	6.9	0.3	651	53	115	6	39	2

roughly coincide. So in addition to this table of average values, many of which are very representative of their respective distributions, we report via histograms that show the full range, relative frequency at each attribute level, and selected statistics like mean and sampling error (Appendix A).

One striking pattern is similarity among forest type groups; for example, percent mortality volume (MortVolPct) for Douglas-fir and True Fir and Pine and Larch is remarkably similar. Basal area, trees per acre, and canopy cover were all substantially greater in Douglas-fir and True Fir than in Pine and Larch in every sub-region, and canopy cover was much greater in Northern California and Klamath than the other two sub-regions. Such patterns are consistent with expectations, but the sizable FIA sample provides strong statistical support for such conclusions.

Perhaps more importantly, we hope these histograms provide a useful context for comparison against any particular stand contemplated for hazard reduction. If these attributes are available for such a stand, it is easy to consult the distribution representing its type and sub-region to see where it lands—is it at the high hazard end of the spectrum, or somewhere in the middle? If post-treatment hazard attributes can be computed or estimated, how far through the distribution will the stand be moved? Does treatment put it at the low hazard end of the histogram, or leave it somewhere in the middle? The answers may differ among hazard descriptors, and it is up to the manager to prioritize among these.

These histograms also provide the user with the option of considering different hazard thresholds than were assumed for this analysis. By summing up the proportions for histogram bars, it is easy to see how much of a landscape rates as hazardous for nearly any threshold. For example, in Pacific Northwest Interior Pine and Larch, about half of stands would rate as hazardous with respect to mortality volume percent using a threshold of 50 percent versus the approximately 63 percent that rate hazardous using our 30 percent threshold.

A baseline for comparing fuel treatment outcomes and the characteristics of stands amenable to fuel treatment

These current conditions data provide a foundation for the fuel treatment effectiveness and feasibility analysis reported on in Chapter 11. It is useful to compare these histograms representing ALL forests with the histograms in Appendix C associated with Chapter 11; the set of stands for which effective treatment is possible often has pre- and post-treatment distribution of hazard descriptors that are different from these all-forest histograms.

Conclusion

The objective of this chapter was to provide context on the scope of the task of implementing fuel treatments across the synthesis area. Most of the synthesis area would benefit from some level of treatment to either reduce fire hazard or to realign forests to put them within the historical range of mixed fire regime conditions. As noted in chapter 4 there are several factors that have led to these changes over a century of management.

Further Reading

Barrett, S.; Havlina, D.; Jones, J.; Hann, W.; Frame, C.; Hamilton, D.; Schon, K.; Demeo, T.; Hutter, L.; Menakis, J. 2010. Interagency fire regime condition class guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website], [Online]. Available: www.frcc.gov [2012, June]. (Provides the methods and protocol for determining the fire regime condition class.)

Hann, Wendel J.; Bunnell, David L. 2001. Fire and land management planning and implementation across multiple scales. International Journal of Wildland Fire. 10(4): 289-403. (Provides a summary of options for planning and implementation at different spatial scales.)

Section II: Fuel Treatment Planning and Implementation in Dry Mixed Conifer Forests of the Northwestern United States

Chapter 6

Integrating Wildlife Habitat into Fuels Planning and Implementation

Chapter Rationale

During our interviews, wildlife was often described as a challenge to implementing fuel treatments:

- Land allocation for threatened and endangered or sensitive species limits the ability to implement fuel treatments in the best location or in locations with the greatest fuel hazards.
- Wildlife habitat needs conflict with hazardous fuels reduction goals.
- Fuels reduction treatments are limited in time or space to avoid impacts to important wildlife habitat elements (for example, dens) or seasons (for example, nesting season).
- Improved communication among resource specialists who specialize in vegetation and fire management and those who work with wildlife is needed for fuel treatment planning and implementation.

Introduction

Wildlife habitat is a critical element in many fuel treatment decisions, and treatments may need to be designed and implemented in concert with habitat needs of the different wildlife species of conservation concern within and near a treated area. We do not attempt to summarize habitat needs by species or by region because the lists vary depending on the agency and they also change from year to year and place to place.

In our interviews with wildlife biologists and managers, a recurring issue was the need to improve communication among resource specialists that specialize in vegetation manipulation (for example, silviculturists and fuels specialists) and those that work with wildlife. To better understand their perspectives, we asked wildlife biologists to identify the concerns and questions that proposals for fuel treatments typically produce. We organized this chapter around those questions with the aim of enhancing communication and integration of wildlife elements in fuels planning and implementation. The objective is not to provide the exact answers to these general questions but to identify the types of information (with reference to a literature synthesis) that can be collected as a starting point for planning and discussion among specialists.

Which Habitat(s) Will the Fuel Treatments Impact and for How Long?

For some wildlife species, knowledge of their exact habitat requirements may be incomplete; however, key habitat elements for specific wildlife species have usually been identified. Wildlife species occur in all plant communities and stand conditions. An individual species and its use of a given habitat will vary depending on how specific environmental conditions fulfill habitat requirements; therefore, any type of fuel treatment will also influence wildlife habitat management as it alters these conditions. As forests regenerate and develop, wildlife habitats change, creating variability in the species that use the different stages of forest development (Johnson and O'Neil 2001; Morrison and others 2006; Reynolds and others 1992). Disturbance, succession, productivity, and species composition drive changes in stand conditions (Morrison and others 2006; Pilliod and others 2006). These four drivers are particularly important in dry mixed conifer forests because in combination they provide a diversity of vegetative compositions and structures over time and space. Moreover, because dry mixed conifer forests are intermixed with both dryer and wetter forest types (which add complexity to the landscape and provide a level of heterogeneity), the forest type characteristics may favor integration of fuel treatments and wildlife habitat objectives. In terms of fuel treatment planning needs, important habitat elements to consider include: sensitivity of habitat, tree or cover type, density, diameter of the trees, canopy cover, patch size, fragmentation and edge effects, snags, down wood, and connectivity. Understanding these wildlife habitat elements and their importance may help improve fuel treatment planning and provide an avenue for effective communication between disciplines. Understanding these elements in space and through time provides the basis for treatment proposals that can integrate forest composition and structure (in other words, desired conditions) at multiple scales to meet multiple resource management objectives.

Composition and structure of the habitat

Each wildlife species has habitat requirements related to dominant tree species, a range of tree diameters, densities, crown cover, and size of habitat patches. These elements can be readily mapped at various spatial scales to quantify potential habitat both spatially and temporally (Ecosystem Research Group 2010; Reynolds and others 1992). Additionally, inventory information, such as Forest Inventory and Analysis (FIA) data, can be used to incorporate other associated habitat elements (for example, snags and down wood) that can also be used at broad spatial scales. Finer-scale information from stand inventories at the project scale can include these and other habitat elements to evaluate conditions within project areas. It is important to assess treatment effects on the type and amount of habitat at multiple scales to judge threshold amounts and the distribution of habitat modified by site-specific proposals. This type of information can help answer the common questions of why here and why now?

Sensitivity of habitat

How much value does the landscape have for a particular species? If habitat is abundant, there may be more flexibility in implementing fuel treatments. However, if the landscape contains critical habitat and in limited amounts, then more attention may need to be given to setting up the fuel treatments for the habitat needs of that species. For example, the Yaak River drainage in northwest Montana provides important habitat for Canada lynx, a threatened species; therefore, fuel treatments conducted in this drainage require careful consideration of lynx habitat needs for breeding, feeding (snowshoe hare), resting, and other requirements.

Fragmentation and edge

Fragmentation is the level of heterogeneity that negatively affects the ability of a particular species to disperse for breeding or obtain critical resources (Saunders and others 1991). However, not all species are equally affected by the spatial structure of the landscape, and a high degree of fragmentation may be needed to begin affecting a particular species. Also, definitions of heterogeneity and fragmentation vary in different landscapes. Tews and others (2004) explained this concept in the context of a heavily used cultural landscape such as central Europe. In central Europe, an increase in forest patchiness likely increases species diversity as more potential habitat is added. However, disruption of formerly closed-canopied, tropical forests likely decreases diversity as a result of habitat fragmentation. Normally, heterogeneity can enhance wildlife habitat for some species. Thus, species of interest and their habitat needs may dictate when a landscape can be considered fragmented or heterogeneous. In addition to affecting longevity, the current composition, structure of landscapes, and fuel treatments also support heterogeneous landscapes because they can alter fire behavior and the post-fire environment, which, in turn, can favor heterogeneous forest structures and compositions favorable to wildlife species. Therefore, creating heterogeneity can be mutually beneficial to both wildlife habitat needs and fuel treatment objectives. The challenge is in balancing heterogeneity and fragmentation. This is best accomplished by considering wildlife needs prior to planning treatment locations so that integration occurs early in the planning process.

An edge is the location where plant communities meet or where successional stages or vegetation conditions within a plant community intersect (Thomas and others 1979b). Edges host the mingling of different vegetation complexes; thus, they tend to be more biologically diverse. Edges create ecotones, which tend to have higher species diversity than the adjoining plant communities. The contribution of an edge to habitat richness is a function of the types of forest stands that come together at an edge and the specific type of habitats and habitat elements that are created.

Two types of edges are inherent and induced edges (fig. 6.1). An inherent edge is one that is produced by abrupt changes in soil type (forest versus meadow), topographic differences (north versus south facing ridge tops), or geomorphic differences or changes

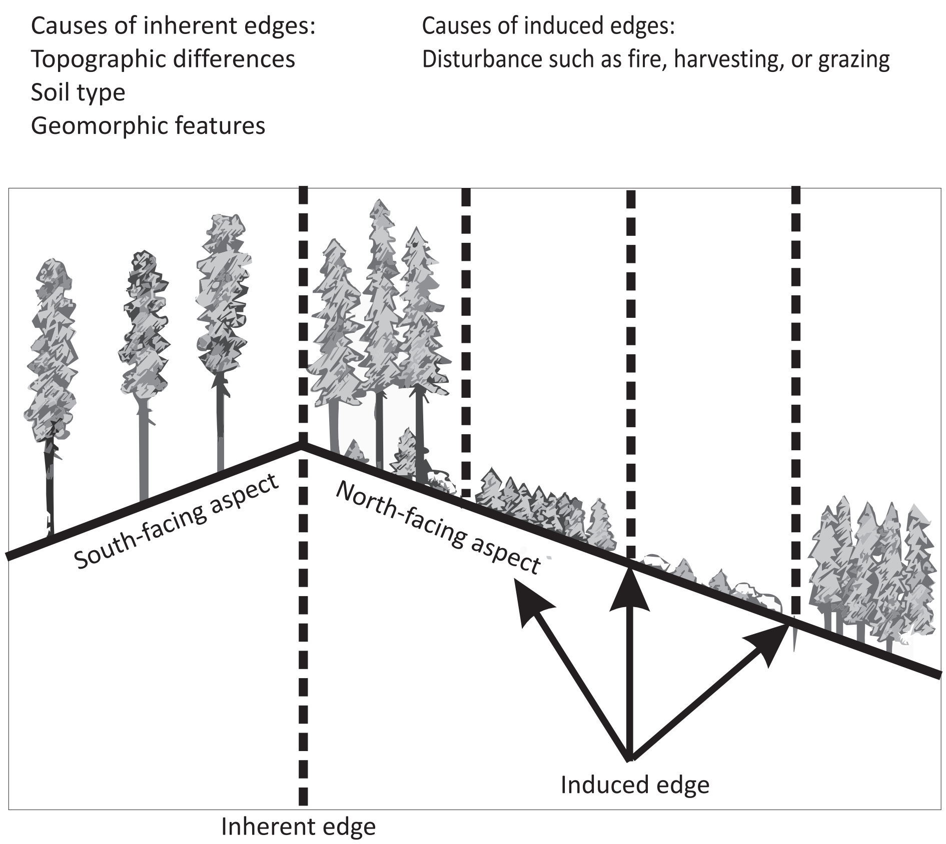


Figure 6.1. Examples and causes of inherent and induced edges (adapted from Thomas and others 1979b).

in microclimate. Induced edges occur from disturbance such as wildfire, disease, insects harvesting and prescribed fire. Many dry mixed conifer forests have inherent edges between different forest types. In these cases, geomorphic differences often drive the variability. For example, on south facing aspects in northern Idaho, inherent edges occur between western redcedar (located in draws) and grand fir on hillsides and Douglas-fir sites occurring on ridges (fig. 6.2). Induced edges are relatively short lived compared to inherent edges that occur between north and south aspects. The value of an edge at providing habitat for wildlife species is dictated by the amount of edge (length, width,

Figure 6.2. Induced edge created by prescribed fire in northern Idaho. The top photograph is forest type change (western redcedar on left/Douglas-fir on right). The bottom photograph shows two forest developmental stages induced by harvest. The foreground is a young forest and background is a mature forest.

and configuration) and the level of contrast between the two communities coming together. A measure of contrast can be illustrated in transition zones between different fire types. In the Bitterroot fires in western Montana, many regenerated sites did not burn at the same level of severity as the surrounding forest (fig. 6.3), creating a dramatic contrast at the edge. However, a transition between a surface fire and torching fire may show a less dramatic contrast between the two post-fire outcomes. Thus, the boundaries and variability within and outside the treatments can be important for both wildlife habitat and altering fire behavior and providing an avenue for integration of wildlife habitat features.

Snags

Figure 6.3. Induced edge caused by wildfire in the Bitterroots where regenerated sites did not burn as severely as surrounding forests.

Snags provide habitat for fungi, mosses, lichens, invertebrates, birds, and mammals (fig. 6.4). Maintenance of a certain abundance of snags is a common wildlife management principle (Morrison and others 2006; Pilliod and others 2006; Reynolds and others 1992; Thomas and others 1979a). Wildlife use of snags depends on the successional stage of the surrounding community (fig. 6.5) and the internal and external characteristics of the snag (fig. 6.6). Snags progress through successional changes from death of the tree to final decomposition (fig. 6.7). Depending on the species and the fire history of a particular area, a snag may exist for years to decades (Smith 1999). Each stage in the decay process provides a habitat element for a different suite of species. There are hard snags and soft snags, with soft snags developing from hard snags through decomposition. A western larch will take much longer to produce a soft snag in comparison to a grand fir. Also, soft snags are relatively rare because their longevity is shorter than hard snags—they simply fall down. Due to changes in forest composition over the past

Form of life	Uses of snags	Examples
Fungi, mosses, & lichens	Decayed wood is a growth substrate	Fungus, Moss, Lichen
Invertebrates	Spaces under bark serve as cover and places for feeding	Pseudoscorpion, Moth, Beetle, Ant
Birds	Cavities for nesting or roosting	Flicker, Nuthatch, Pileated woodpecker
Mammals	Bats roost under loose bark and cavities used for dens, resting, or cover by other mammals.	Bat, Flying Squirrel, Martin

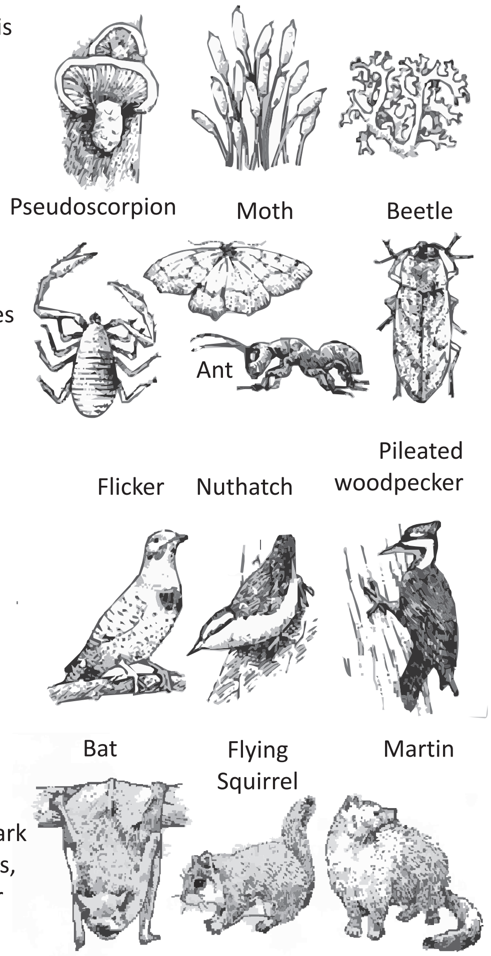


Figure 6.4. Snags provide habitat for various life forms (adapted from Thomas and others 1979a).

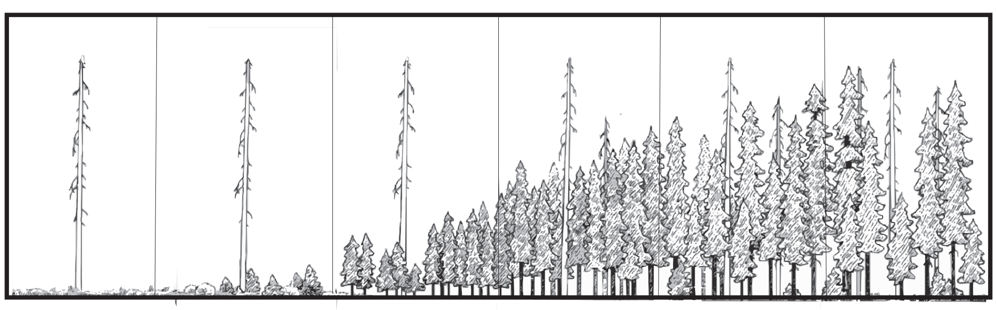


Figure 6.5. Wildlife use of snags depends on the structural stage of the surrounding community (adapted from Thomas and others 1979a).

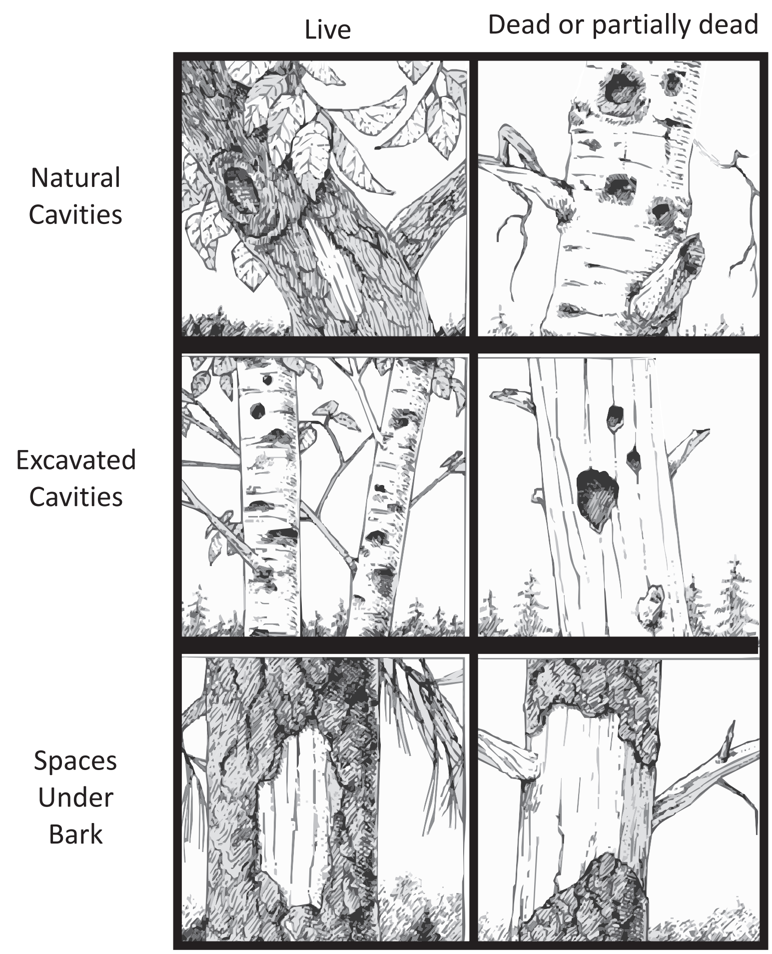


Figure 6.6. Examples of cavities in live and dead trees (adapted from Thomas and others 1979a).

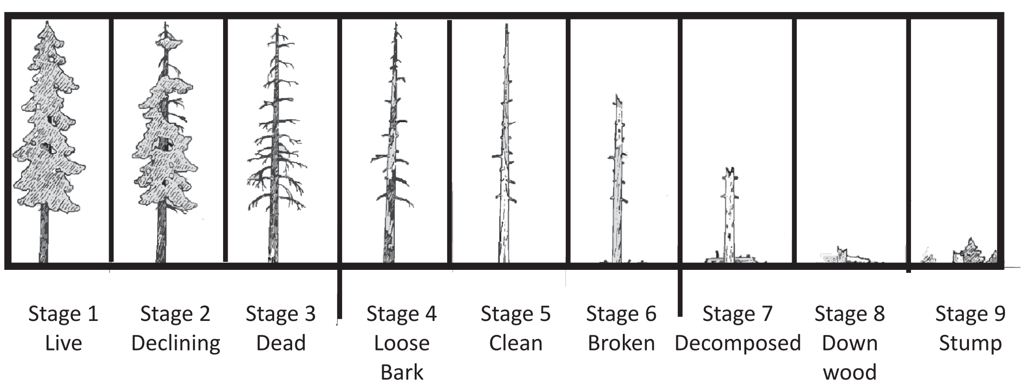


Figure 6.7. Snags progress through successional changes from live trees to death to final decomposition (adapted from Thomas and others 1979a).

century, many shade-tolerant trees such as grand fir, hemlock, and Douglas-fir are more available today, providing short-term soft snags. By contrast, long-lived seral species such as ponderosa pine and western larch that provide persistent snags are now less common on the landscape, making them a more important habitat attribute.

A number of snag characteristics are important for wildlife (Bull and others 1997; Thomas and others 1979a). For example, loose bark (stage 4) is important for bats (fig. 6.7), and excavating woodpeckers such as the pileated woodpecker prefer large-diameter (20+ inch dbh) stage 6 trees (fig. 6.7). Similarly, pileated woodpeckers will nest in a snag that is surrounded by trees but tend to avoid nesting in snags in freshly harvested sites. The size and height of snags also influence their habitat value. Figure 6.8 shows the number of cavity-nesting species that use two snags of different heights and diameters. Snags that are 10 ft or less tend to have a larger suite of cavity nesters than taller snags irrelative of diameter. However, a range of different species use snags based on their diameter, and the preferred size varies by species and location. Within the dry mixed conifer forest range, some locations grow larger trees than others, and large-diameter trees tend to stand longer than small-diameter trees. Therefore, managers may need to acknowledge that the size of snags to target for habitat enhancement may be location specific.

Understanding the preferred snag size for targeted wildlife species provides direction for maintaining snags. Taller snags are more hazardous, and if wildlife in a certain area utilize snags 10 feet or shorter, it may not make sense to maintain the taller snags. Furthermore, identifying tree species that are utilized by specific wildlife species is an important consideration. Field guides such as the one developed for the Interior Columbia River Basin (Parks and others 1997) can be helpful. Another source of information on the relative abundance of snags of various sizes is obtained from assess-

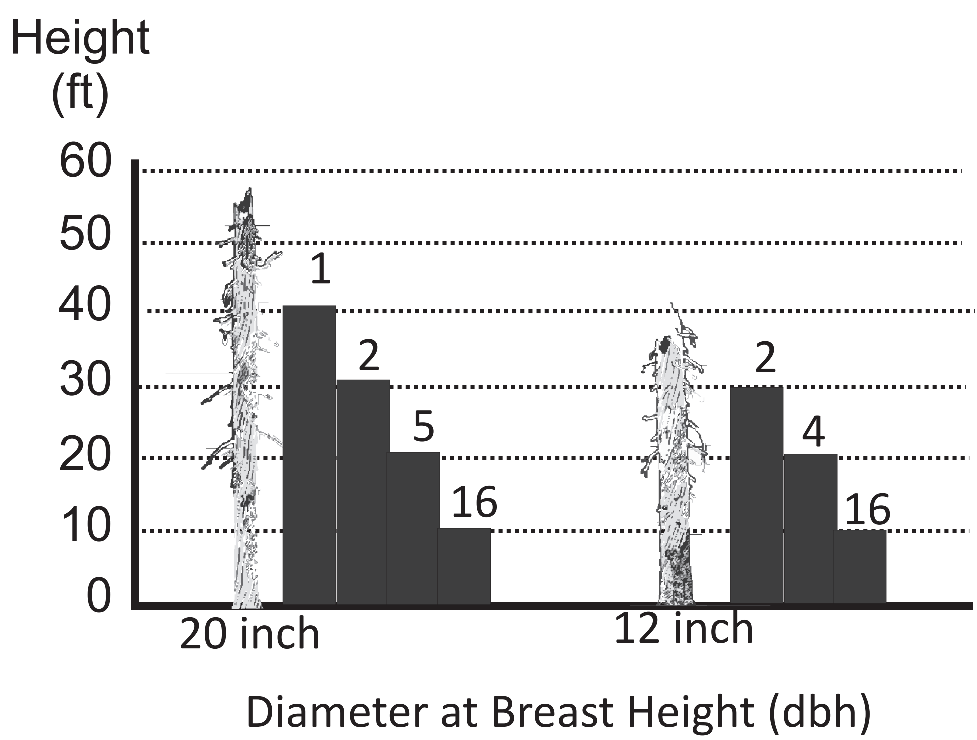


Figure 6.8. The diameter and height of a snag influences habitat value (adapted from Thomas and others 1979a). Values above bars refer to the number of cavity nesting species of birds that use snags of different diameter and height.

ments using FIA inventory data. It has been noted that large-diameter snag abundance is relatively rare across the landscapes that contain roads compared to those areas without roads. Similarly, areas under historical fire regimes contain more snags than areas in fire excluded areas. This type of information can help inform snag maintenance by diameter groups to satisfy habitat needs of wildlife species that depend on this forest element (Bollenbacher and others 2008, 2009a, 2009b)

Dead and down wood

Dead and down wood (often 1000 hour fuels or greater) also provide habitat for many wildlife species (Bull and others 1997; Maser and others 1979a) (fig. 6.9). For wildlife purposes, logs are used for hiding cover, feeding (both consumption and food storage), and reproduction (for example, denning and mating rituals) (fig. 6.10). For example, stage 1 snags such as down logs can offer hiding and thermal cover for snowshoe hares, lynx, fisher, pine martens, and porcupines, particularly if there are support points that offer access to portions of the log off of the ground. These logs can also be used as lookout posts for chipmunks and, when elevated, can be bridges for a variety of species and drumming sites for grouse. Also, these logs provide feeding sites for lizards, chickadees, and red squirrels. As the log progresses in decomposition, it sits closer to the ground and provides cover for gopher snakes, shrews, chipmunks, or voles. As the log decays, the bark becomes a location where tree frogs and western skinks can catch invertebrates. By the time a log reaches stage 4, the interior may be soft enough for burrowing and can be used by shrews, deer mice, and voles. Even when logs reach stage 5, small animals use them for reproduction, feeding and caching, and protection. Bull and others (1997) found that the larger the log the better for wildlife habitat; however, the minimum size identified for habitat purposes tended to be 12 to 15 inches dbh for species such as western larch, Douglas-fir, ponderosa pine, and lodgepole pine.

Connectivity

Connectivity generally refers to movement among animal populations in vegetation corridors, with more precise terms such as emigration and immigration used to describe the nature of the movement. Connectivity helps keep populations stable, decreases the likelihood of extinction, and maintains genetic variation (Mills and others 2003).

Corridors provide biodiversity protection to rare and endangered species as well as a wide range of other species (Forman 1995). Connectivity is a structural attribute that affects corridor function. Habitat is functionally enhanced by higher connectivity. Wildlife survival may depend on access and use of corridors as they provide connectivity between different areas. Corridors can also play a key role in providing dispersal routes for recolonization following disturbance, which may create local extinctions. Wildlife species tend to not live in corridors but primarily use them as an avenue for movement. Corridors are dynamic and can be created or removed over time and space, a change that is often dependent on wildlife needs. In some cases, such as in riparian areas, which have many unique attributes that favor multiple species, corridors may be present and protected for long periods of time.

Corridors can be integrated into fuels management since they can contribute to creating heterogeneity in fuels, altering fire behavior and effects. It is important to understand the historic role fire played in shaping vegetation corridors to help determine current desired conditions (Quigley and others 1997a). Definitions of connectivity in terms of the seral stages of vegetation and what constitutes a corridor for a specific wildlife species are a scale-dependent issue.

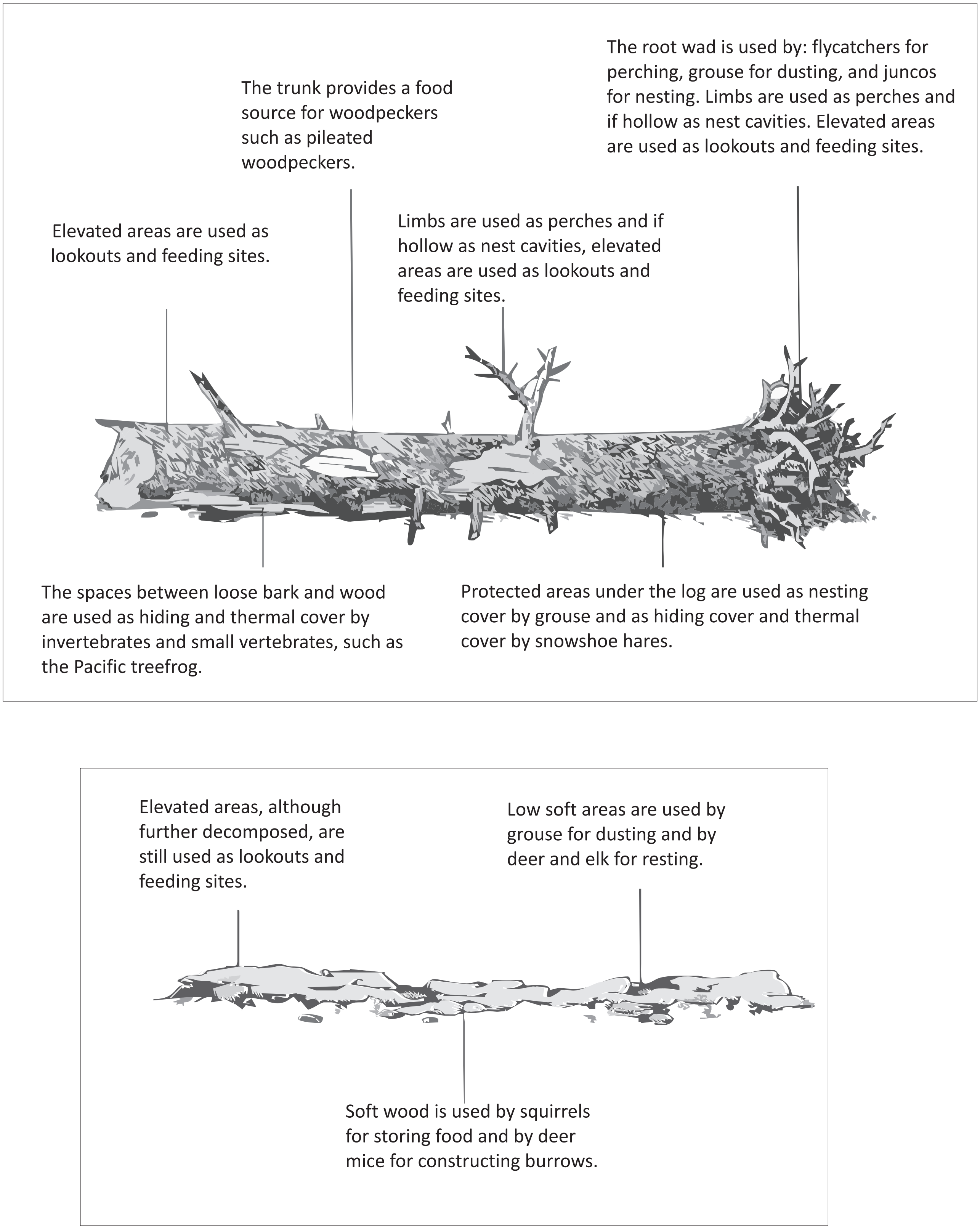


Figure 6.9. Two logs at different decomposition stages show the diversity of structural features important for wildlife (adapted from Maser and others 1979).

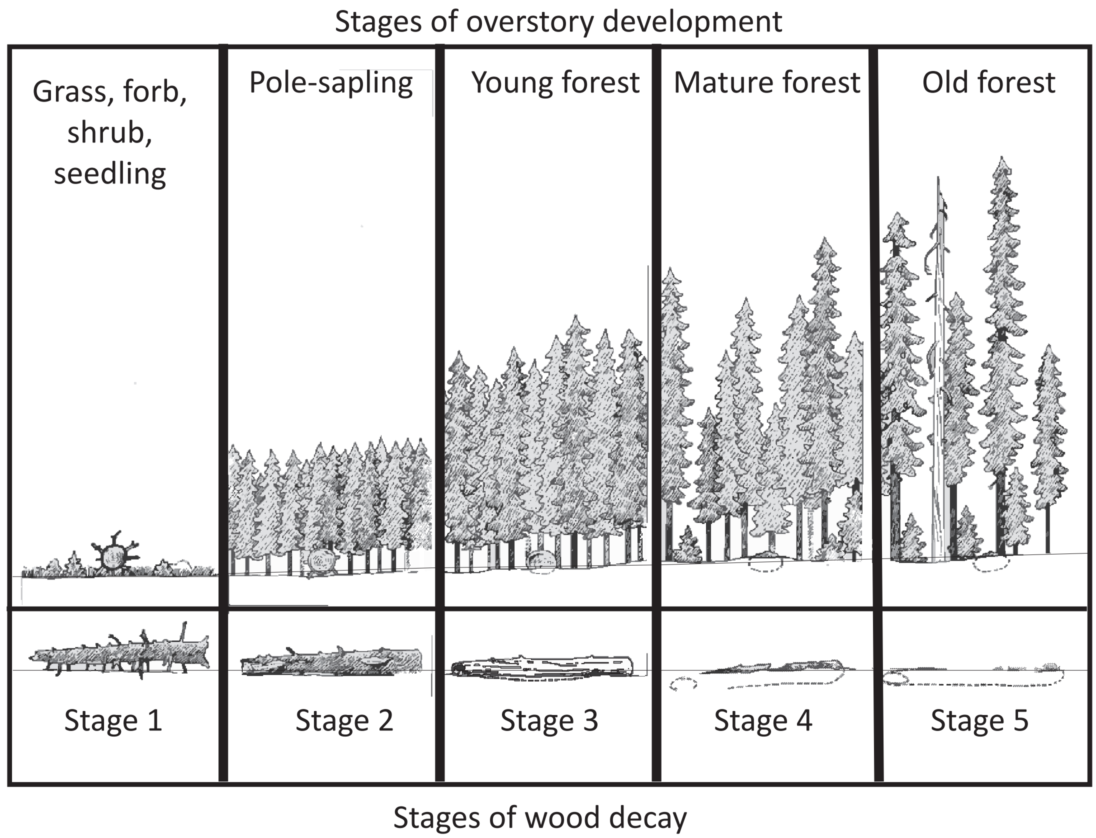


Figure 6.10. Log succession from a sound, intact log to a nearly decomposed log (adapted from Maser and others 1979).

Which Wildlife Species Are in the Proposed Planning Area?

A variety of methods may be used to understand and identify desired conditions for wildlife habitat and to determine which wildlife species will be impacted (positively or negatively) by a fuel treatment. The simplest and most direct method is to discuss how a particular fuel treatment might affect habitat elements for a species with wildlife biologists who have direct knowledge of specific wildlife habitat elements. Developing this partnership early in the planning process, prior to the reconnaissance period, can inform the silvicultural diagnosis and prescription process by helping identify desired stand conditions to be evaluated against current stand conditions, thereby providing insight into treatment alternatives (Bollenbacher 1995; Sturtevant and others 2005). These discussions are also the time when unit locations can be proposed, treatment size can vary, residual canopy or protected areas can be identified, and other habitat elements can be integrated into the treatment planning.

Manager comment: The job of the fuels specialist is to work with a wildlife biologist and silviculturist to quantify the risk of habitat loss from severe wildfire with and without treatment and weigh those risks against the impacts from a fuel treatment. In this way, the decision maker can make informed decisions and communicate about relative risk to the habitat.

In addition to site-specific habitat attributes, wildlife population dynamics, insect outbreaks, and wildland fires function at larger landscape scales; therefore, adding wildlife habitat elements to a landscape evaluation may be beneficial. In the Okanagan-Wenatchee National Forest Restoration Strategy (2010), a landscape evaluation technique was developed to allow managers to analyze and prepare restoration plans that integrated vegetation, fire, wildlife habitat, aquatics, and road networks. The Ecosystem Management Decision Support Framework (EMDS 3.0.3, Reynolds and Hessburg 2005) was used to combine the specific information needed for the evaluation. The land managers used a seven-step process, including a step (step 4) dedicated to identifying key wildlife habitats and restoration opportunities. First, managers identified the key species of interest. Then, for each of the identified species in the particular landscape evaluation area, they (1) determined the location and amount of habitat within the landscape evaluation area (they also compared the current amount and configuration of habitats to historical and future reference conditions); and (2) identified habitat restoration opportunities and priorities that could be integrated with the other resource priorities (and determined which priorities would be carried into project level planning). This approach allowed for evaluation of wildlife needs at a much broader landscape scale and integration into other resources issues. It also helped identify specific elements or priorities that could be brought down to smaller spatial scales for individual projects. This strategy may be helpful for integrating a particular wildlife species and its habitat into fuels planning.

The Beaverhead-Deerlodge National Forest in southwestern Montana demonstrated another example of landscape planning at the scale of an entire National Forest. This area utilized landscape simulation modeling to quantify habitat for multiple species in space and through time, incorporating disturbances from fuel treatments, bark beetles, and wildfire to gain insight into the relative persistence of wildlife habitat (Ecosystem Research Group 2010).

How Will the Proposed Treatment Impact the Habitat and Wildlife Species?

This answer to this question is a function of the habitat elements being affected in the proposed action. There have been several documents that have addressed the impacts of wildfire and fuel reduction treatments (mechanical and prescribed fire) on wildlife and wildlife habitat in recent years (Kennedy and Fontaine 2009; Lehmkuhl and others 2007; Pilliod and others 2006; Saab and others 2007). For example, Pilliod and others (2006) provided a synthesis to help fuels planners, fire managers, and National Environmental Policy Act specialists evaluate the potential effects of fuels reduction treatments on terrestrial vertebrate and invertebrate species in dry coniferous forests of the western United States. In that document, Pilliod and others (2006) described the general impacts of thinning and prescribed fire on structural habitat features and the implications for different wildlife species, including forest carnivores, ungulates, small mammals, bats, raptors, cavity-nesting birds, general birds, reptiles, amphibians, and invertebrates. Based on this information, the authors developed the web-based Wildlife Habitat Response Model. This model provides information about specific species habitat associations, life history requirements, potential predators, and hazards, and how a fuels reduction treatment might influence those factors. The information is based on published literature about species/habitat relationships and provides information about how different fuel treatment activities might alter the habitat.

Kennedy and Fontaine (2009) provided a synthesis of wildlife response in dry coniferous forests within the Fire and Fire Surrogate Network (FFS). The FFS consisted of operational-scale experiments that tested silvicultural and prescribed fire restoration treatments. These research sites were found throughout the western United States and some were located within the geographic scope of this synthesis, including: northeastern Cascades (ponderosa pine/Douglas-fir/grand fir), southern Cascades (ponderosa pine and white and red fir), Blue Mountains (ponderosa pine/Douglas-fir), and northern Rocky Mountains (ponderosa pine/Douglas-fir). Other sites outside of the geographic area covered in this synthesis that could still be useful include the central Sierra Nevadas (Sierran mixed conifer), southern Sierra Nevadas (Sierran mixed conifer), and the southwestern plateau (ponderosa pine). The goal of this document was to provide land managers with a resource that allowed them to easily access species-level data related to prescribed fire and mechanical fuels reduction treatments. The ultimate goal was for managers to use the data presented in that document to answer the following questions (from Kennedy and Fontaine 2009):

1. Does information exist on the response of the species in the project area to the proposed treatment(s)?
2. Is the response of the species to the treatment consistent (in other words positive, negative, no response)?
3. Is the response short-term or is there evidence of long-term responses?

See "Further Reading" for more information from Kennedy and Fontaine (2009).

Conclusion

This chapter was designed to:

- present key wildlife habitat elements (although not all elements will be important for a particular wildlife species);
- provide important concepts and ideas to encourage discussion between vegetation managers and wildlife and range biologists; and
- provide vegetation managers with key questions that may help identify wildlife needs when planning fuel treatments.

Wildlife biologists identified these questions as important considerations when planning integrated fuel treatments.

Further Reading

The following documents provide more details and information to interested readers. We found these books to contain extensive and detailed discussions of wildlife-habitat relationships.

Johnson, David H.; O'Neil, Thomas A. 2001. Wildlife-Habitat Relationships in Oregon and Washington. Oregon State University Press, Corvallis OR. 736 p. (Presents the state of the science for amphibians, birds, mammals, and reptiles and their terrestrial, freshwater, and marine habitats in Oregon and Washington. The information was designed for local, watershed, state, and regional applications. Where appropriate, some of the information and overall framework may be applicable in surrounding states and provinces. This is a large, detailed reference book that may be appreciated by wildlife biologists, conservation biologists, or others with a keen interest in wildlife-habitat relationships.)

Morrison, Michael; Marcot, Bruce G.; Mannan, R. William. 2006. Wildlife-habitat relationships: concepts and applications. 3rd ed. Washington DC: Island Press. 493 p. (Detailed description and discussion of wildlife-habitat relationships that may be of interest to those who wish to learn the nuances of wildlife habitat.)

Pilliod, David S.; Bull, Evelyn L.; Hayes, Jane L.; Wales, Barbara C. 2006. Wildlife and invertebrate response to fuel reduction treatments in dry coniferous forests of the western United States: a synthesis. Gen. Tech. Rep. RMRS-GTR-173. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 34 p. (This summarizes fuel treatments influences on different wildlife species.)

Kennedy, Patricia L.; Fontaine, Joseph B. 2009. Synthesis of knowledge on the effects of fire and fire surrogates on wildlife in U.S. dry forests. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 132 p. (Summary and details of the literature cited can be found in Appendix 1 through 3. Appendix 1 provides information on the different wildlife response studies, time since disturbance, type of disturbance, and different wildlife types [amphibian, raptors, birds, bat, small mammal, and large mammal]. Appendix 3 summarizes information from a quantitative analysis of wildlife response to the FFS treatments.)

Chapter 7

Planning and Conducting Integrated Fuel Treatments

Chapter Rationale

In our interviews, many fuel managers emphasized that the primary challenge in conducting fuel treatments is planning. Consequently, this chapter is focused on integrating fuel treatments with other objectives. The following questions guided organization of this chapter:

- How does the ecology of the dry mixed conifer forests influence fuel treatment planning and implementation?
- When addressing a variety of objectives, how do we increase consideration of fuels in planning?
- What decision support tools are available for fuel treatment planning?

Introduction

Planning and implementing fuel treatments primarily involves working through a number of important challenges. When fuel treatments are combined with multiple-objective management, achieving fuel treatment goals sometimes becomes (or at least appears) more limiting. Fuel treatments are a subset or type of vegetative treatment in which the specific purpose of the manipulation is to alter fire behavior and/or effects. Therefore, it is important to understand what fuel treatments cannot do (see Reinhardt and others 2008 in Further Reading):

- Forests cannot be fireproofed; all live and dead vegetation are fuel and can burn in undesirable ways given the proper conditions.
- A fuel treatment is not static; vegetation grows and develops over time and thus repetition of treatments may be necessary.
- Unless properly positioned, treatments may not have the intended effect. Even large and extensive landscape fuel treatments may not reduce the size of area burned. However, they can alter post-fire outcomes, protect areas of concern, and provide suppression opportunities.
- Depending on the residual forest structure and composition, fuel treatments may not improve forest health.
- A fuel treatment may not slow down rate of fire spread and could potentially increase how fast a fire moves through a treated area.
- Some vegetation manipulation treatments such as mastication may increase fuel hazard in the short term by increasing fine surface fuel loadings, which take time to decompose; however, in the long-term, they may decrease the fuel hazard by treating ladder and surface fuels.

Defining the short- and long-term objectives of the fuel treatment early in the planning process is the most important and critical step. Included in the objectives is the recognition of what fuel treatments cannot do. For example, short-term objectives such as protecting values at risk and providing suppression opportunities or firefighter safety (which will be tested during a wildfire event and will only be useful for one or two days) drive the rationale behind a fuel treatment. However, because forests continue to grow and develop, including fuel treatment maintenance and the periodicity of this maintenance may need to be incorporated into the objectives. So when a fire does occur, the treatments perform as expected or planned. Also, if one of the objectives for a fuel treatment is to support active fire suppression and firefighter safety, the placement and juxtaposition of fuel treatments could potentially influence fire management decisions such as where to place burn outs, fireline building, retardant drops, and structure protection. Thus treatments can be more successful in aiding wildfire response when there is time to initiate these activities prior to the arrival of a wildfire, including time to identify safety zones and escape routes (for example, Graham and others 2009). The probability of a wildfire burning through any particular fuel treatment is low, and the period that a fuel treatment performs its intended function may only last one day. However, if never exposed to wildfire, the treatment will be present on the site for decades to centuries; therefore, long-term benefits warrant consideration in terms of post-fire outcomes or fuel treatment objectives over the long haul. Forest type, objectives, spatial extent of the treatment area, current forest conditions, and surrounding forests influence which combination of treatments will create the most effective post-fire outcome or response opportunities. Also, it is important to acknowledge vegetation dynamics; understanding growing space and the potential response of vegetation to treatments will influence treatment planning. The bottom line is that the exact set of treatments will vary for each site, and one type or combination of fuel treatments will not fit all situations (Graham and others 2007).

Social, economic, or political aspects will also influence the kind, location, and intensity of treatments. For instance, prescribed fire is often restricted near communities because of smoke limitations and the inherent risk for its escape. On public lands, achieving the desired forest conditions and implementing management actions may often meet multiple and sometimes conflicting objectives. For example, on the east side of the Cascade Mountains in Washington, several forests modified by timber harvest and fire exclusion are providing habitat (late-seral grand fir) for the endangered northern spotted owl (Everett and others 1994; Hessburg and others 1994). These conditions are not resilient to fire and warrant treatment, but fuel treatments cannot be applied because of potential impacts to owl habitat. In addition, many of the areas with northern spotted owl habitat also contain homes, lodges, and other infrastructure where use of prescribed fire and vegetation removal are often limited. Accordingly, the most applicable fuel treatment for modifying burn severity and/or fire behavior often is diminished in extent and degree of manipulation because of the regulatory, administrative, or social acceptance of treating forests.

This chapter focuses on concepts to consider when planning fuel treatments as the primary objective or as one of many objectives. There is no specific recipe or perfect treatment combination; there are always benefits and trade-offs among a seemingly infinite number of treatment options that can be applied over time and space. Thus, the best suite of fuel treatment combinations incorporates science, experience, values, and common sense to create innovative solutions when treating fuels within the context of multiple-objective projects.

Important Concepts, Challenges, and Trade-Offs

In dry mixed conifer forests, fuel treatment planning and implementation are often limited by the forest conditions that result from past management actions (see chapter 4). The resulting dense forests containing late-seral species (for example, grand fir and white fir) can lack large, fire-resistant trees, which limits the type and intensity of treatments that can be used. Because of the productivity of dry mixed conifer forests, the longevity of a fuel treatment will be reduced. Therefore, plans should include some consideration of continued surface and crown fuels maintenance. In addition, a mosaic of fuel treatments may need to be dispersed over time and space to allow the landscape to grow and develop diverse successional stages and plant community structures and compositions that reflect vegetative patterns found in either a low severity or mixed severity fire regime (Halolfsky and others 2011; Perry and others 2011). In places where low severity fires maintained historical composition in the dry mixed conifer forests, vegetation pattern and structure could reflect similar attributes in dry ponderosa pine forests. However, these sites will need continued disturbance over time to maintain the preferred forest structures and compositions. In the mixed severity fire regime, treatment location is related to the diversity of topography, soils, and other biophysical settings (refer to Chapter 2).

Dry mixed conifer forests are fire dependent. Thus, even when fuel treatments are not the primary objective, we recommend that some discussion concerning fuels and fire occur during objective development. For example, timber production requires a long-term investment, and in fire-dominated forests, wildfire always provides an element of uncertainty. It may be beneficial to integrate fuels planning into timber management plans, thus accepting and addressing the potential for wildfires and recognizing potential post-fire outcomes. Within a wildlife management context, if there is a place particularly important for a wildlife species a question such as: if a wildfire occurred what would be the result? Discussing this question may lead to identifying opportunities to protect or minimize damage by implementing fuel treatment in strategic locations. Including fuels planning with other objectives makes articulating the management objectives for a particular area one of the most difficult tasks in forest management, but it is a critical element that must be done with care and thought. By fully understanding the treatment objectives, desired forest conditions can be described over time and space and a series of treatments can be designed to meet these other objectives.

Manager comment: The planning stage of a fuel treatment involves many players that represent a variety of resources. Each resource specialist has a stake in the outcome of treatments and is tasked with the responsibility of maintaining the integrity of their specific resource. Often, impacts of the proposed treatment negatively affect one resource while benefiting another. These impacts require compromises by some resource specialists to reach a mutually agreeable management action.

Heterogeneity Matters

Manager comment: The need for effective fuel treatment patterns on the landscape is not limited to extreme fire weather. In fact, fuel treatments can be least relevant in periods of extreme fire behavior, which often create conditions beyond limitations of a reasonable treatment prescription. Large fires under less extreme fire weather conditions may be managed for cost containment, reducing firefighter exposure, or resource benefits, and the spatial patterns of treatments should be designed for these potential objectives as well.

Manager comment: For mixed conifer forests, where multiple objectives such as maintenance or improvement of ecological and/or wildlife values are desired, it is often not possible to reduce surface and ladder fuels to a point that adequately diminishes potential for transitions to crown fire. Often, the best way to harmonize competing objectives is through a mix of treatments of the fuels profile (to an acceptable degree), combining the removal of canopy fuels with the creation of small openings

and preservation of other patches with tighter crown spacing. In this way, a crown fire may initiate, but it won't gather momentum as it is constantly disrupted by areas of wider spacing and gaps and will drop back to the ground. If the fire weather and fuels conditions realign for the fire to climb back into the canopy somewhere else, if designed properly, the fire will again hit an opening and drop back to the ground (it is very difficult to simulate this design in current computer models, by the way).

Again, this prescription may or may not be acceptable given the objectives of the fuel treatment. Treating for particular types of fire behavior may only be acceptable in areas far from the wildland urban interface. Any treatment, however, will result in fire behavior (and effects) that is an improvement over the untreated alternative; however, this may not be a surface fire that can be safely attacked by ground forces. In the right location, more severe fire behavior may be desirable (and would contribute to resource benefits). A more hazard-centric and homogeneous prescription is likely to fit better in treatments designed to create defensible space. Or perhaps in the same project area as the canopy fire treatment described above, but near a road that fire mangers determined is a good location for a fuel break. There are some areas where fire management control, firefighter safety, and hazard reduction are always favored over other objectives.

Often, creating heterogeneity within treatments and across landscapes is the most efficient way to meet multiple objectives. This idea has been suggested by a number of researchers. Reinhardt and others (2008) suggested that a more realistic approach to fuel treatments is to "focus on creating conditions in which fire can occur without devastating consequences." Larson and Churchill (2012) suggested that restoration efforts in ponderosa pine and mixed conifer forests introduce or retain spatial variation in structure and composition within treated areas. Modeling approaches have indicated that the effect of many patches containing slow-burning fuels dispersed throughout the landscape in a herringbone pattern can disrupt the forward progress of a fire and create variability in the intensity of the fire as it moves across the landscape (Brackebusch 1973; Finney 2001). Although an ideal strategic distribution of fuel treatments may not be possible and may be difficult to implement, the key point of the herringbone pattern concept suggests that heterogeneity matters when integrating fuel treatment planning. Jain and others (2008) advocated heterogeneity and diversity across landscapes and presented different ways to implement heterogeneous treatments. Graham and Jain (2005a) developed the free selection silviculture system to allow for the introduction of heterogeneity. Perry and others (2011) stated that a "large amount of edge and clumpiness in forest structure, composition, and seral status within and among patches provides a rich intermingling of habitats for early, mid-, and late-successional specialists as well as a variety of individual species." The authors also stated that forests that evolved with mixed-severity fire regimes "exhibit temporal as well as spatial variability." These suggestions all advocate some form of heterogeneity to be introduced into management scenarios designed to address a variety of integrated objectives.

Manager comment: While the concept of Finney's herringbone design was described as intriguing, placement of the herringbone design often is not practical due to values at risk, land ownership patterns, and many other factors. In addition, other disturbances do not work as specifically as fire; beetle attacks do not necessarily follow the herringbone pattern.

There is evidence that a range of forest structures and compositions can be resilient, including closed canopy conditions (Jain and others 2007). For example, self-pruning increases canopy base heights and shading from the overstory canopy reduced growth rate of understory fuels, thus retarding ladder fuels development (fig. 7.1). Areas that

Figure 7.1. Canopy base height in the photograph (way above individual's head) was created through self-pruning. When trees grow close together, the lower branches die, raising the canopy base heights. Photo by Theresa B. Jain, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

have very little amounts of dead fuels and that contain succulent plant species and an abundance of live fuels can be also very resilient (fig. 7.2). Plantations treated with prescribed fire to remove surface fuels and promote herbaceous and young tree compositions tend to be less susceptible to crown fire. Dry forests with large, tall, fire-resistant trees that have high canopy base heights dispersed throughout the landscape also are very resilient (Agee and Skinner 2005). The biophysical setting is likewise an important element to integrate into fuels planning. Topographic diversity drives the mixed fire regime and favors a variety of species compositions and structures. For example, high-density, multi-story stands that contain western redcedar in Idaho are often located in stringers adjacent to dry mixed conifer (Daubenmire 1980) (fig. 7.3). These locations have deeper soils, higher relative humidity, more soil moisture, or lower air temperatures than the neighboring slopes or ridges.

Integrating heterogeneity, biophysical setting, and a variety of structures on the landscape is essential for achieving desired conditions for the dry mixed conifer forests. The challenge in developing landscape-scale treatments is getting from the conceptual stage through planning to implementation. The following section discusses this process and provides examples of where others have been successful at developing a planning process that favors integration over mitigation.

Figure 7.2. Different successional stages and past treatments affected fuel moisture and subsequent resilience in wildfires. The combination of past treatments, lack of dead fuels, and roads contributed to preventing this plantation from burning. Photo by Theresa Jain, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station after the 2000 Bitterroot wildfires.

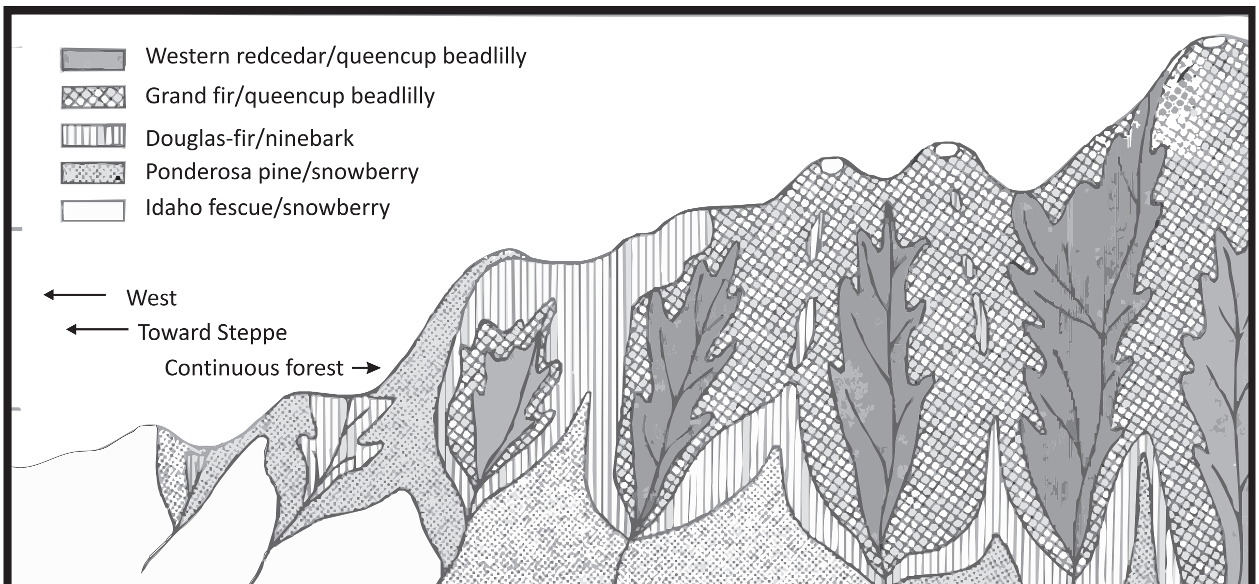


Figure 7.3. Illustration of the topographic relationships to vegetation within dry mixed conifer forests (adapted from Daubenmire 1980).

Manager comment: Prioritizing the location of a fuel treatment is often dictated by many factors besides the most strategic location. Often, fuel treatments are located where National Environmental Policy Act (NEPA) (Environmental Assessment [EA] or Environmental Impact Statement [EIS] has been conducted and signed) has already been performed, such as in timber harvest units or wildlife enhancement areas. Although these areas are not always the best location for strategic placement, many managers cited that these integrated projects allow more efficient use of monetary and personnel resources. On some forests, fuel treatments are limited to the WUI (wildland urban interface), while others have the ability to treat outside the WUI. In many areas, County Wildfire Protection Plans (CWPP) designate where the treatments are placed. When managers were given the opportunity to be strategic with their fuel treatment placement, they considered factors such as wind flow patterns, topographic features, roads, fire history, and past management activities. In addition, higher prioritization of areas with mid- to late-seral species can provide opportunities to promote early seral species like ponderosa pine, western larch, and Quaking aspen.

Integrated Treatments

Manager comment: The key to any management activity is to have a clear understanding of the objectives and goals you are working toward. The objectives identified by the resource specialists were similar across the region: modify fire behavior and severity, create resilient forests, protect values at risk, and provide for firefighter safety. How these objectives were achieved often differed greatly depending on several factors, including: location (WUI versus non-WUI), funding, risk of litigation, market availability, leadership, smoke limitations, and wildlife concerns.

Manager comment: One of the most important elements in planning is to clearly define the desired future condition of the treatment that meets the objectives and goals. Too often, the focus of fuel treatments is on the immediate short-term benefit of the reduction in fire hazard. We know that forests are dynamic and maintenance of low fire hazard is required. However, funding and short-term planning windows prevent the successful and guaranteed planning and implementation of future maintenance treatments.

Manager comment: A blend of approaches can be melded in a single planning effort, with greater emphasis on hazard mitigation near structures or other areas of concern (for example, municipal watersheds) and on meeting other objectives in other areas.

There are unique differences between planning processes that emphasize mitigation and those that attempt integration. Mitigation planning first develops a proposed action with only one or a few objectives in mind. The action is then evaluated in terms of its potential impact on other values such as wildlife species and soil productivity. Based on results from this analysis, treatments are mitigated to avoid direct impacts on these other values. Integration is the blending of multiple resources that lead to the integrated design of objectives which are then used to develop management strategies for treatment placement and design (Stockmann and others 2010). This favors communication and mutual learning among different disciplines. The success of using integrated management strategies is dependent on the relationships among the involved managers, the public, and the element of uncertainty associated with alternative development of treatments.

To address many of the challenges in planning, we highlight an integrated planning process outlined in a publication by Stockmann and others (2010) that focuses on integrated fuel treatment projects and a multi-objective process called Integrated Assessment Modeling. This recent case study, completed within a dry mixed conifer forest in our synthesis area, illustrates many of the challenges expressed in our discussions with managers.

An integrated planning process focuses on multiple-objective planning rather than single-objective planning from the beginning of the project. It favors a transparent and interactive process that offers opportunities for understanding ecosystem complexity, stakeholder positions, and clear articulation of decision trade-offs and benefits. Stockmann and others (2010) stated it as: "application of the approach… especially within a collaborative working environment… may increase support for more balanced land management decisions. This has the potential to improve implementation success rates and reduce time and resources spent in litigation."

Stockmann and others (2010) provided a conceptual framework for integrating fuel treatments into multiple resource objective project planning. It is intended for use with projects attempting to develop and place strategic fuel treatments. The authors' objective was to use various reporting metrics in project-level NEPA analysis to summarize how well alternatives meet the project objectives and to identify costs, benefits, and trade-offs. Monitoring can confirm our expectations or force us to modify those expectations in future projects. If these measures are used in multiple projects and with adequate monitoring, it may be possible to make statements eventually about how well agency programs are meeting the descriptions of alternatives in Forest Plans. So, for the most part, the approach is focused on the NEPA environmental analysis more than proposal development (Keith Stockmann, personal communication). The iterative process Stockmann and others (2010) described uses five steps.

Inclusion of stakeholder preferences and concerns begins early in the process at Step 1. Having stakeholders involved in early planning stages creates a collaborative decision framework that can be useful throughout the planning process. When alternatives are constructed and refined in Step 5, the process provides another opportunity for stakeholder input that ties back to Step 1.

Step 1. *"Convert resource assessments and observations into a preliminary set of management issues, leading to a 'purpose and need' statement with clearly stated management objectives."*

The goal is to identify relevant resource issues and use them to create management objectives. There is no limit to the number of objectives. Moreover, the list may actually contain objectives that address fire and fuels, vegetation, watershed, fisheries, soils, wildlife, aesthetics, economics, social contributions, air quality, and threatened/endangered/sensitive plant species. Objective statements should be short and concise. An example statement to address fire and fuels is: change forest structure so that crown fire is less likely to occur under more extreme fire conditions. These conditions could be further specified based on identified thresholds, such as the 80th percentile in fire weather conditions. An objective statement for wildlife may be to ensure habitat attributes for Federally listed, threatened, or sensitive species are identified and incorporated into the fuel treatment design. This step is also used to evaluate whether the identified objectives complement or conflict with each other, and can assist teams attempting to identify whether each objective should be meshed into the analysis and the degree to which it should be emphasized.

Manager Comment: It is a challenge to integrate wildlife habitat preferences that require dense, multi-storied, and open conditions.

Step 2. *Develop an integrated assessment modeling framework by translating management objectives, including the no action alternative, into quantitative and qualitative metrics (measureable characteristics that gauge some quantifiable component) that evaluate the diversity of alternatives can meet the identified objectives.*

The purpose is to develop ways to measure, model, and evaluate whether the proposed action will achieve the objective or objectives. A variety of techniques and decision-making tools can be used to quantify whether a treatment has achieved an objective (in the absence of an actual test from a wildfire). For example, if the objective is to reduce the extent of crown fire, then FARSITE, FlamMap, FFE-FVS, and other tools can indicate potential changes in the fire type from a crown fire to a surface fire (refer to Appendix B for list of possible tools). An objective related to fisheries may involve the removal or improvement of man-made barriers from streams to allow upstream or downstream passage of aquatic species. Another objective may be to improve the resiliency of vegetation to insects and disease by favoring resistant species compositions. This could be evaluated by performing growth predictions for resistant species such as western larch, sugar pine, and ponderosa pine using FFE-FVS. Although these resource objectives may not be the primary reason for a fuel treatment, they could be considered as secondary benefits and identified as options during the analysis process.

In addition, those who implement the decision, including contract officers, sale administrators, burn bosses, harvest and road engineers, should early and periodically throughout the planning phase be included in the discussions to ensure that the plans are economically and physically feasible.

Manager comment: Models and decision-making tools are used to validate expert knowledge and address uncertainties.

Step 3. *Develop a format to display the benefits and trade-offs among the metrics that were developed in Step 2 for each alternative.*

Two components are in Step 3: (1) decide on the technique or method that will be used in the comparisons among alternatives, and (2) weight the relative importance of the various objectives identified in Step 1. Ultimately, the goal is to produce a performance (benefit) and trade-off report. This step provides a quantitative mechanism for evaluating and communicating the trade-offs among planning team members, partners, stakeholders, and decision-makers.

Step 4. *Assign metric values for the no-action alternative.*

The no-action alternative reflects the current conditions, which provide a baseline for comparison between the treatment alternatives, and can help evaluate the effects of future changes from the different treatment options. The goal is to predict how these conditions are expected to change with treatment.

Step 5. *Develop the various silvicultural treatments and/or activities suitable for meeting objectives.*

Once different management scenarios are developed, an analysis is conducted to evaluate resource trade-offs across the management alternatives, thus refining the preferred alternative. Ideally, treatments or activities can fulfill multiple objectives. For example, road upgrades on haul routes can reduce sediment delivery to fish-bearing streams and allow passage of aquatic species. Another example is removing ladder fuels that compete with large trees for water and nutrients to increase residual large tree growth.

A number of challenges consistently occur in the planning process. Accounting for uncertainty when modeling alternatives is always a challenge because of the inherent assumptions and simplifications in the modeling process; however, model results are useful in showing different results as a function of different scenarios. Therefore, it is important to document selection criteria, assumptions, limitations, and rationales used.

A good example of documenting the process is the use of a silvicultural prescription, which details the timing and treatment specifics throughout the life of a forest (silvicultural system). Although the prescription may be modified over time, it incorporates long time frames and addresses treatment longevity.

The Silvicultural Prescription

Manager comment: Although there are places for targeted treatment planning with single objectives, integrated fuel treatments help to develop an awareness and understanding of complimentary and contradictory resource objectives and the need to develop prescriptions that best harmonize them.

Silviculture is founded on the basic science and life history of forests. The practice is designed to integrate forest ecology and silvics (scientific study of trees and their environment) in order to develop treatment pathways over time and space (a silvicultural system) that influence vegetation growth and dynamics for achieving forest management objectives. Developing a silvicultural prescription requires integrating knowledge from multiple disciplines (fig. 7.4). Within a fuel treatment context, this involves working with fuels specialists and fire practitioners. If the project is driven by multiple objectives, integration will require a close working relationship among many disciplines. A silviculturist is trained to ask the right questions and think through a process in order to develop a series of fuel treatments that address single or multiple objectives.

We suggest five concepts that support a silvicultural system that may be useful in developing a fuel treatment strategy (Step 5 from the integrated management process) (Nyland 2002). These concepts should be integrated to subsequently determine what treatments can be applied in which locations to meet the desired future conditions over the short and long term.

1. *The interaction of vegetation composition and structures with manmade, physical (fire), biological (insects and disease), and environmental (wind and ice) disturbances.* All vegetation is a fuel for fire, so it is important to understand vegetation (fuel) dynamics.
2. *Plant vigor in relation to biomass produced, growth rate, and disturbance resistance.* This knowledge can be used to understand treatment longevity.
3. *How current conditions coupled with changes in canopy opening and soil substrate influence the subsequent growth and development of vegetation.* This can be related to the potential effect of management actions on fuel dynamics.
4. *The combination of treatment types and timing of implementation best suited for the site and the landscape to meet future desired conditions over time and space.* In terms of fire resilience, this requires working with experts in fire behavior to understand large fire movement over a landscape and determine the best location for fuel treatments. In addition, it involves developing an understanding of the diversity of vegetation that will create heterogeneity in post-fire outcomes.
5. *Identify the forest structure, composition, and landscape pattern that will meet multiple objectives given the resources available for implementation.* In this sense, implementation resources include elements such as road access, slope limitations, and economic feasibility. Therefore, to develop the silvicultural prescription, specific characteristics of the critical infrastructure need to be identified.

A suite of treatments can be developed that incorporates all of these concepts, including:

- **Harvests:** can include regeneration cuts, improvement cuts, and other large tree manipulation; often not considered a “fuel treatment.” Harvests introduce younger age classes and different forest compositions.
- **Surface treatments:** prescribed fire, grapple piling, or mastication, determined by the residual tree species and goals for treating surface fuels.
- **Regeneration potential:** covers both natural and planting regeneration and can include all plant species (not only trees), recognizing which species may respond to the treatment and their potential growth rate and potential fire resistance.

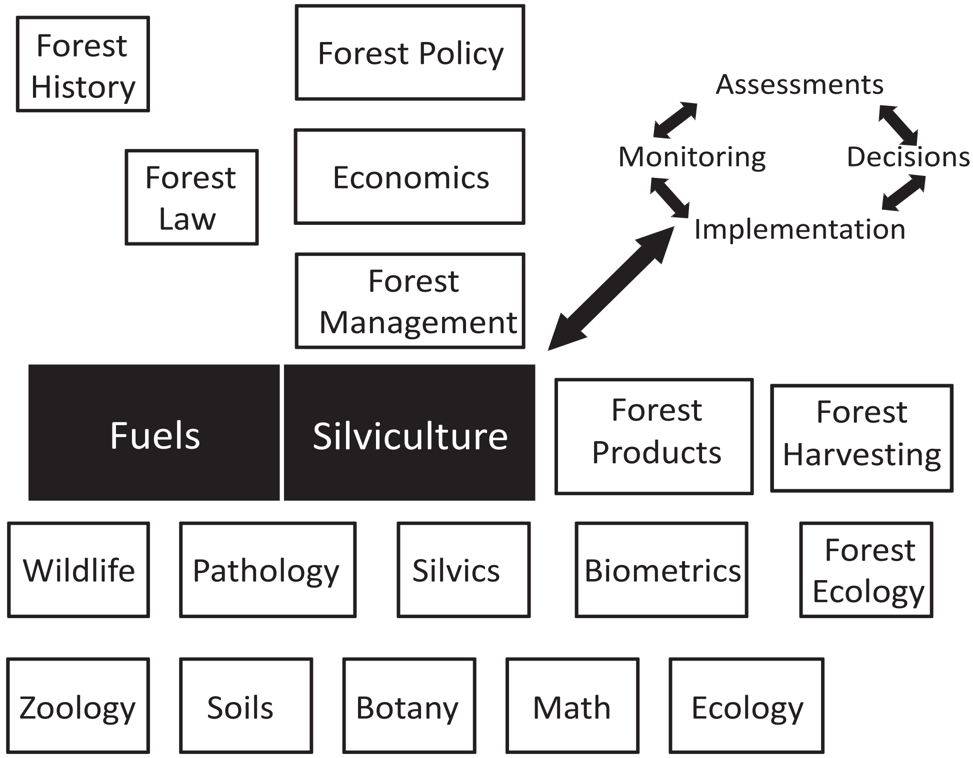


Figure 7.4. In fuels treatments, silviculture is the art and science of integration. A silviculturist cannot work alone, but rather depends on a variety of expertise to describe a set of desired future conditions. Designing fuel treatments alone from the site to the landscape takes expertise in fuels and silviculture. However, integrating other objectives into fuel treatment planning takes the interaction among several disciplines to blend and develop a fuel treatment (adapted from Nyland 2002).

- **Tending:** can include thinning, cleanings, weedings, and pruning to address ladder fuels.
- **Placement, patch size, and spatial variation within patches**: the concept of landscape silviculture (applying treatments with an eye on the landscape effects) is evolving. Specific prescription parameters such as the placement of treatments, juxtaposition of patches, and favoring irregularity in composition and structure within patches are being developed and tested (for example, Abry and others 1999; Graham and Jain 2005; Graham and others 2007; Jain and others 2008; Larson and Churchill 2012).

It is important to note that a silvicultural prescription is not developed in isolation, but rather through strong leadership from decision-makers and partnerships across all disciplines involved in planning the project. The silviculturist has the education and expertise to write the prescription but depends on the planning team to provide key elements, desired future conditions, and implementation skills (such as preparing a burn plan). A significant "artistic" component is required to bring all of the elements together to: (1) write a prescription; (2) implement the treatments given the infrastructure available (contracting, funding, accessibility, and personnel); and (3) monitor outcomes and apply adaptive management. While these steps can guide the process, they are not a strict recipe that can be applied to every situation. Fuel treatment planning requires a great deal of experiential learning.

Communication in Planning

Interdisciplinary teams, science teams, and a variety of multiple discipline teams can be defined as the "pooling of tangible resources, such as information, money, labor, etc., by two or more [individuals] to solve a set of problems which neither can solve individually" (Gray 1985: page 912). When working with multiple agencies and stakeholders in resource management, the term "collaboration" is often defined as "building understanding by fostering exchange of information and ideas among agencies, organizations, and the public, and providing a mechanism for resolving uncertainty" and "effective decision making though processes that focus on common problems and build support for decisions" Wondolleck and Yaffe (2000: page 8).

Although Sturtevant and Jakes (2008) emphasized these elements in collaboration, many of the same elements can be used when working within interdisciplinary teams (fig. 7.5). Fuel treatment planning begins by assessing the risk (Why here?), describing the goals (Why now?), and evaluating the alternatives. This evaluation often involves sharing information, building relationships, pooling resources, and conducting outreach among disciplines. Strong leadership coupled with a team that incorporates many of these elements can lead to shared responsibility, implementation of an integrated fuel treatment, mutual learning, and building of relationships and networks.

Many of these elements also apply to successful integrated science teams. In some cases, these teams are more ecologically driven and may be focused on basic science. However, interdisciplinary applied science also considers the social, economic, and ecological aspects of research questions. The success of integrated science teams depends on establishment of common goals (research objectives) and collaboration among scientists who may have different views. Thus, trust, collaboration, and relationship building are essential on scientific teams. Scientists pool resources (people, funding, and instruments) and learn from each other through considerable information sharing. Outreach is necessary when building teams and obtaining the needed science expertise to address a research problem. The entire process is built on mutual learning, and scientists judge research effectiveness through social acceptance of the relevance, impact, and scope of the research results.

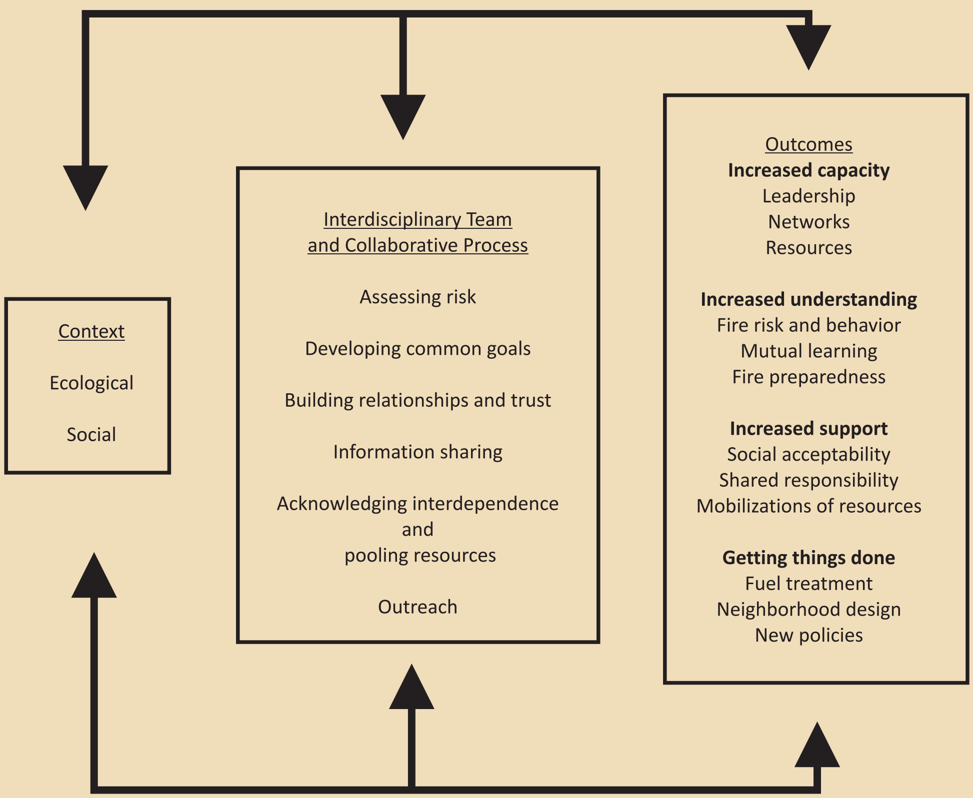


Figure 7.5. Sturtevant and Jakes (2008) described the elements of teamwork and collaboration that lead to successful outcomes in fuel treatment planning. There are three main categories: context, team or collaborative process, and outcomes. Teams can use these basic concepts in fuel treatment planning.

Decision Support Tools

Manager comment: There are many decision support tools and all must have a use, otherwise they would not have been developed. However, some are too complicated or cumbersome and there is insufficient time to learn them or use them effectively. The tools that are commonly used tend to have regional or national support.

Integrated management sometimes requires use of decision support tools, and many are available for fuels management; we identified more than 20 fuels planning tools. Some tools such as BehavePlus, Fire Area Spread Simulator (FARSITE), and FlamMap address fire behavior. Others such as FOFEM, BlueSky, and Consume focus on fire effects and smoke emissions. The Fuel Characteristic Classification System and Natural Fuels Photo Series characterize fuels. Internet portals such as FIREHouse and FRAMES are available to access tools. Some portals offer training and downloadable software for sets of tools as well as a variety of fire specific databases that provide information on fire history, plant responses after fire, and Forest Inventory and Analysis. There are also decision support user interface platforms for obtaining and using results from multiple models (for example, the Interagency Fuels Treatment Decision Support System).

With the expanding availability of tools, managers are challenged to determine which best fits their needs. It can also be difficult to find the time, data, and expertise to use a tool effectively. We have identified some published guides that are designed to help managers choose among the variety of decision support tools available and use them effectively (see Appendix B for short summaries and links to appropriate web sites).

Conclusion

A key aspect of integrating fuel treatments is to fully define the conditions under which they are designed to modify wildfire behavior and burn severity. This can be done through description of the targeted forest conditions over time and space. It is also important to integrate multiple objectives and develop a fuel manipulation design that weaves together a variety of forest structures and compositions. Compromises are always made in integrated planning, but if the integration begins early in the planning process, a thorough evaluation of the benefits and trade-offs can be clearly articulated. Successfully creating resilient forests may require more than a focus on the number of acres treated; treatments must also be evaluated in terms of the effectiveness at achieving fuel treatment objectives and other important elements in dry mixed conifer forests. Strong partnerships and working relationships with silviculturists, wildlife biologists, hydrologists (including those who implement the decision), and stakeholders are critical to develop integrated management strategies.

Further Reading

Peterson, David L.; Evers, Louisa; Gravenmier, Rebecca A.; Eberhardt, Ellen. 2007. A consumer guide: tools to manage vegetation and fuels. Gen. Tech. Rep. PNW-GTR-690. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 151 p. (Provides the most comprehensive summary of available tools as of 2007. We list those tools and others that have been developed since 2007 in Appendix A. In addition to providing a list of tools, the authors also described how to select a particular model, provided examples of how to use the decision support tools at various spatial scales, and suggested steps to take in the planning process.)

Stratton, Richard D. 2006. Guidance on spatial wildland fire analysis: models, tools, and techniques. Gen. Tech. Rep. RMRS-GTR-183. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p. (Summarizes and guides spatial wildland fire analysis, including models, tools, and techniques. This report guides fire managers, planners, and specialists in analyses using FARSITE, FlamMap, REPAT-Term, KCFAST, and FireFamily Plus. The authors also provide detailed instructions on conducting a spatial fire analysis and explicitly list the geographic information systems data requirements and considerations of conducting an analysis, including calibrating the models.)

Reinhardt, Elizabeth D.; Keane, Robert E.; Calkin, David E.; Cohen, Jack D. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. Forest Ecology and Management 256(12): 1997-2006. (Describes the reality of what fuel treatments can and cannot do. This publication provides a good discussion of the benefits and trade-offs associated with fuel treatments.)

Stockmann, Keith D.; Hyde, Kevin D.; Jones, J. Greg; [and others]. 2010. Integrating fuel treatment into ecosystem management: a proposed project planning process. International Journal of Wildland Fire 19(6): 725-736. (Describes a process that was applied on the Bitterroot National Forest.)

Chapter 8

Mechanical, Chemical, and Biological Fuel Treatment Methods

Chapter Rationale

Depending on location, timing, and objectives there are a variety of methods that can be used alone or in combination to treat different fuels. In chapters 8 and 9, we describe the methods available for treating fuels. Chapter 8 focuses on mechanical treatments and herbicide and biological techniques. Chapter 9 is focused on fire as a tool. We discuss when and where these methods are best suited and present the basics of planning and implementing particular methods. The motivating questions that guided this chapter are:

- What fuels should be treated?
- What is the best mechanical method to treat fuels given the management, physical setting, and economic objectives?
- What are the fuel strata that require treatments?
- What alternative methods are available for treating fuels?

Introduction

There are a variety of techniques to remove or alter plant biomass (live, dead, or decomposed). This chapter provides an overview of three techniques and reference sources that may be useful to pursue for more detailed information. The techniques we discuss in the chapter are mechanical removal or alteration of biomass, which is the most common method used to address fuels. Chemical techniques can be very effective at controlling understory vegetation and there is considerable information on implementation. Targeted grazing by goats, sheep, cattle, and horses is also another option and we highlight a guide that has a focus on treating vegetation using these biological techniques.

Fuel Strata

There are three broad fuel bed types: ground, surface, and crown (aerial fuels). These three broad categories can be further developed into six layers: (1) canopy, (2) shrubs and small trees, (3) low, nonwoody vegetation, (4) woody fuels, (5) moss and lichens, and (6) ground fuels (Riccardi and others 2007; Sandberg and others 2001). Modification of any of these fuel layers has implications for fire behavior, fire suppression, and fire severity.

Canopy Fuels

Canopy fuels are those suspended above the ground in trees, snags, and ladder fuels. These fuels consist mostly of live and fine material less than 0.25 inches. Depending on the forest, its setting, and inherent disturbances, these canopy layers may be simple and uniform such as those that occur in young (30 to 50 years) to mid-aged (80 to 120 years), early seral species such as lodgepole pine and western larch. In contrast, dense and highly complex upper canopy layers often occur in late-seral, dry mixed conifer forests (see chapter 2).

Ladder fuels provide access for flames from a surface fire to climb into the higher fuel layers and tree crowns. Ladder fuels can include lichens and moss, climbing ferns or other epiphytes that live on the trees. Some trees such as western larch are receptive to lichens growing on their stem or on branches due to bark properties. Other ladder fuels include dead branches, vines (such as honeysuckle), leaning snags, and stringy or fuzzy bark such as that of western redcedar. Understory trees that reach the lower crown of the dominant trees can provide a ladder to the upper crown during a wildfire. These essentially bridge the vertical gap between surface and canopy layers. The size of this gap is critical to ignition of a crown fire from a surface fire below. Aerial fuels separated from surface fuels by large gaps are more difficult to ignite because of the distance above the surface fire, thus requiring higher intensity surface fires, surface fires of longer duration that dry the canopy before ignition, or mass ignition from spotting (Byram 1966). Once ignited, high-density canopy fuels are more likely to result in a spreading crown fire (active crown fire) than low-density canopies.

Surface Fuels

Surface fuels consist of grasses, shrubs, litter, and woody material lying on, or in contact with the ground surface (Sandberg and others 2001). Surface fuel bulk densities (weight within a given volume), and size class distribution (for example, number of pieces in 0-0.25 inch, 0.25-1.0 inches, 1.0-3.0 inches, and greater than 3 inches size classes) are critical to frontal surface fire behavior (spread rate and intensity). Other characteristics of surface fuels that determine surface fire behavior are fuel depth, continuity, and chemistry. High surface fire intensity usually increases the likelihood for igniting overstory canopy fuels, but surface fuel types with longer residence times can contribute to drying aerial fuels above a forest canopy, which also leads to torching (when tree foliage ignites and flares up) (Graham and others 2004).

Low nonwoody vegetation includes grasses and low shrubs. Snowberry, spirea, and russet buffaloberry are frequent mid-level shrubs. In the dry mixed conifer forests, the ground level vegetation or surface fuels are often some of the most important components for treating vegetation to influence fire behavior and burn severity. Snowberry, buck brush, willow, and greenleaf manzanita, along with juniper are frequent low to mid-sized shrub species. Depending on the setting, juniper can have both shrub and tree forms. Mosses and lichens grow on rocks and forest floor litter and are sometimes overlooked as a fuel source (Riccardi and others 2007). When dry, they can act as a fuel that may favor smoldering or long-term heating.

The influence of woody debris as a fuel is dependent on the bulk density of surface fuels and size class distribution of fine fuels (which are more critical to frontal surface fire behavior, spread rate, and intensity) than fuel loading alone. The more productive dry forests tend to accumulate relatively high amounts of coarse woody debris (CWD), especially in the absence of fire. For example, on grand fir and Douglas-fir forest types in Montana and Idaho, CWD ranges from 5-20 tons/acre. In contrast, on ponderosa pine forest types in Utah, CWD can range from 5-10 tons/acre, but can quickly accumulate in forests in which white fir are the late-seral species (5-15 tons/acre) (Graham and others 1994).

Ground Fuels

Ground fuels consist of humus, the fermentation layer, surface and partially buried rotted wood. Needles and bark often accumulate at the base of trees and eventually create deep organic layers in which fine roots and ectomycorrhizae of trees and ground level vegetation may accumulate (Graham and others 2000). Ground fuels typically burn by smoldering and may burn for many hours, days, or even weeks if initial moisture contents are high (Frandsen 1991; Hungerford and others 1991). This long duration smoldering can often lead to soil damage, tree mortality (high severity), and smoke (Ryan and Noste 1983; Ryan and Reinhardt 1988; Wells and others 1979). Rotten material on the ground surface is particularly ignitable by firebrands (small twig segments or bark flakes supporting glowing combustion) falling ahead of an advancing fire front (spotting).

Removing Biomass and Fuels

Fuel treatments are designed to meet short-term and long-term fire management objectives. This may include altering fire behavior or influencing post-fire outcomes. If the objective is to create a more resilient fire-dependent dry mixed conifer forest, consequently live and dead vegetation are fuel and thus have the potential to burn. Even the most benign surface fuels will burn during wildfires if they are dry, and fire behavior and weather prevent quick suppression (Reinhardt and others 2008). Thus, all treatments, even if not designated as fuel treatments, manipulate vegetation and subsequently alter fuels.

Determining the specific objectives early in the planning process is critical when designing fuel treatments. Depending on the setting, forest management activities may need to be viewed within the larger landscape when evaluating fuel dynamics and fuel diversity. This is particularly important in the dry mixed conifer forests since a mosaic of different fuel structures and compositions are an important component of many of the landscapes in which they occur.

To aid in this evaluation, there are basic questions to address. Is altering fire behavior the primary concern? Is a treatment designed to support active fire suppression within the fuel treatment area during a wildfire? Is treating fuels the primary objective or is there flexibility in integrating other resource values? Are the treatments designed to create fire resilience in the stand without directly creating space for direct fire suppression activities, while providing options in fire management? What are the long-term implications of the treatment? What are the treatment effects on fuels in the short- and long-term? This section discusses options and elements to consider when addressing these questions.

Treating Fuels to Support Active Fire Suppression

When the treatment objective is to change fire behavior and create protected space for active fire suppression, then biomass removal to aid fire suppression efforts tends to follow the suggestions of Agee and Skinner (2005): (1) reduce surface fuels, (2) increase height to live crown, (3) decrease crown density, and (4) keep large trees of fire resistant species. Moreover, the size of the treated sites may need to be effective at reducing the energy of the expected fire (especially in the case of a running headfire) in order to implement fire suppression tactics. This normally involves creating fuel conditions that will support direct suppression activities or act as control points. Within the fire suppression zone, safe zones and escape routes could be identified during the design phase as well as locations for suppression tactics such as fireline placement, burnouts, and other techniques.

A good example of a successful fuel treatment plan was demonstrated in Warm Lake, Idaho, in 2007 (Graham and others 2009). Warm Lake is located in north-central Idaho on the Cascade Ranger District in Boise National Forest and is a high valued recreation area with vacation cabins and resorts. The District, led by Fire Management Officer Mark Loseke, designed a series of fuel treatments surrounding the Warm Lake Wildland Urban Interface. They identified the values at risk (fig. 8.1), identified the appropriate treatments for the given biophysical setting (fig. 8.2), and implemented treatments between 1996 and 2005.

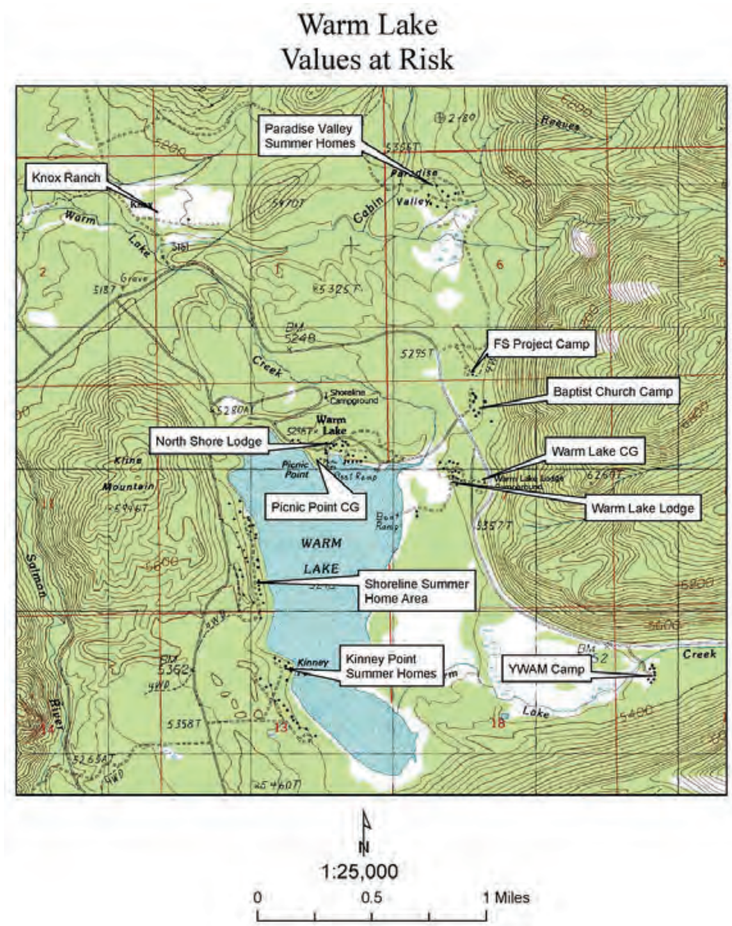


Figure 8.1. Values at risk identified in the Warm Lake Fuels project (Graham and others 2009).

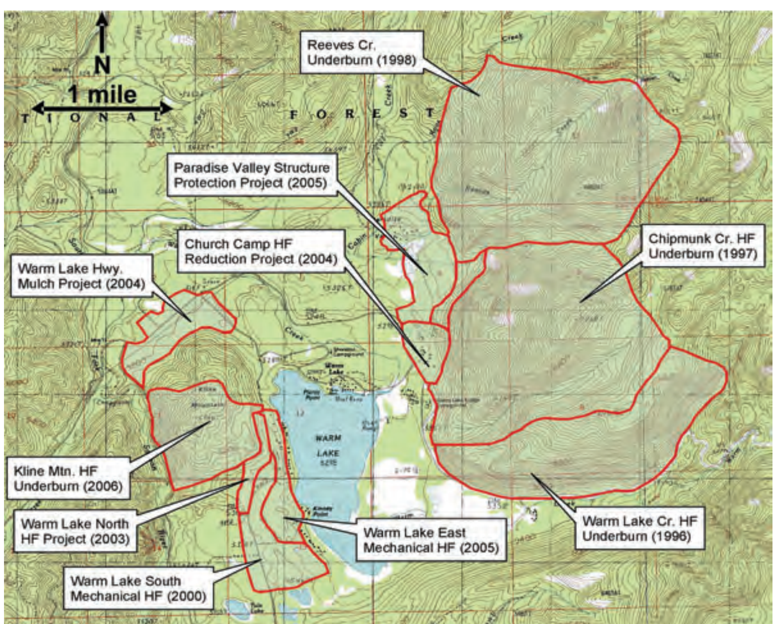


Figure 8.2. Series of fuel treatments that were implemented to address values of risk (Graham and others 2009).

Large prescribed fires (ranging in size from 438 to 2300 acres) were applied in 1996 through 1999, 2004, and 2006. Mechanical treatments were completed in 2000 through 2005 (tables 8.1 and 8.2). Within areas identified for mechanical treatments, canopy base heights were raised, overstory crowns were dispersed, and surface fuels in the form of slash were removed, either through piling and burning or chipping. On the steeper slopes, prescribed fire was used to increase canopy heights and diminish the amount of surface fuels (figs. 8.3, 8.4, and 8.5).

These treatments were tested in August of 2007. The treatments provided fire suppression opportunities because it allowed fire crews to burn surface fuels prior to the wildfire reaching the treated areas. Spot fires were also easily extinguished in the treated areas. The fuel treatments were placed in proximity to the lake, which during the fire serendipitously provided a safe zone for firefighters. In this example, the fuel treatments were placed within the context of the landscape and incorporated both fine scale and broad scale treatment placement. They were large enough in size that fire fighter safety was ensured within the mechanically treated areas and three of the four principles outlined by Agee and Skinner (2005) were met, particularly in the mechanical treatments. As a result, all identified values at risk were maintained. However, the fuel treatments did not stop the wildfires and most likely did not alter the size of the fires. However, the treatments facilitated protection of the values at risk, resulting in minimal damage to infrastructure while reducing safety risks to the firefighters on the scene, which made them successful given the objectives they were originally designed to achieve.

Table 8.1. Prescribed fire was used in and near the Warm Lake Basin to alter the surface and ladder fuels. Treatments began in spring of 1996 and progressed through 2006 (see figure 8.2) (Graham and others 2009).

Project	Year burned	Season burned	Size (acres)
Warm Lake Creek	1996	Spring	480
Reeves Creek	1998	Spring	1,636
Chipmunk Creek	1997	Fall	1,958
Trail Creek	1999	Spring	612
Six-bit Creek	2004	Spring	2,342
Kline Mountain	2006	Fall	438
Total acres			6,348

Table 8.2. The mechanical treatments were designed to remove surface and ladder fuels around the Warm Lake values of interest (see figure 8.1) (Graham and others 2009).

Project	Year	Size (acres)	Treatment combination
Warm Lake South	2000	221	Commercial harvest, hand slash, hand prune, hand pile & burn
Warm Lake North	2003	71	Commercial harvest, hand slash, hand prune, hand pile & burn
Warm Lake Highway	2004	182	Mastication
Church Camp	2004	110	Hand slash, hand prune, hand pile & burn
Paradise Valley	2005	124	Hand slash, hand prune, hand pile & burn
Warm Lake East	2005	59	Hand slash, hand prune, hand pile & burn

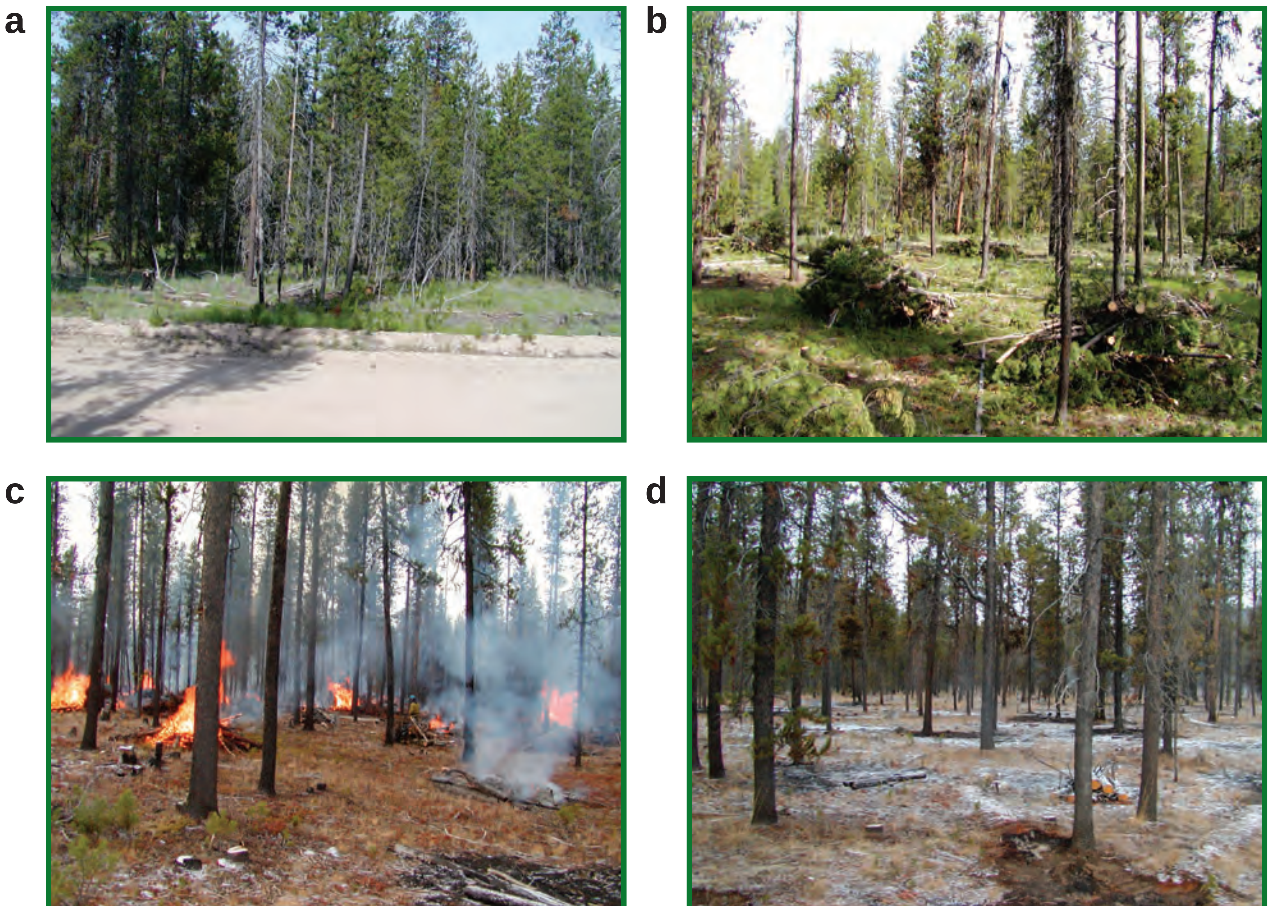


Figure 8.3. The Warm Lake South treatment of ladder and surface fuels. A combination of hand slashing, piling, and burning the piles were used to accomplish objectives. The figure shows (a) before treatment, (b) hand slashed piles, (c) pile burning, and (d) after treatment (Graham and others 2009).

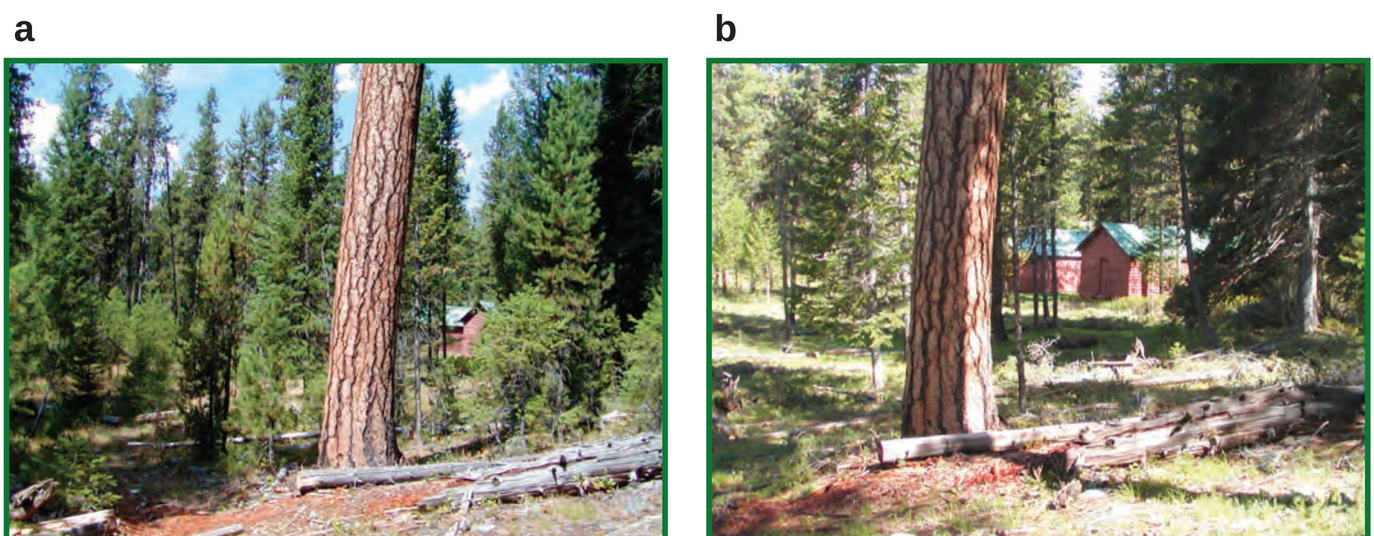


Figure 8.4. Before (a) and after (b) treatment of the Church Camp project. Notice red cabin in background (Graham and others 2009).

Figure 8.5. Before treatment (a), mulching of surface and ladder fuels (b), and after treatment (c) on the Warm Lake Highway Project (table 8.2) (Graham and others 2009).

Treating Vegetation (Fuels) to Enhance Resilience to Wildfire

In dry mixed conifer forests, resilience to wildfire refers to its ability to recover after a wildfire and to have desired post-fire outcomes such as live trees and intact forest soils. Even if a treatment is not specifically designated as a “fuel treatment,” the resulting vegetation will still influence fuel dynamics. Accordingly, a variety of thinning methods can be used to manipulate crown fuels (Graham and others 1999; Peterson and others 2005). These include low thinning or thinning from below, crown thinning or thinning from above, selection thinning or diameter-limit thinning, free thinning, and mechanical thinning. In addition, other types of cuttings include non-commercial and pre-commercial thinning (in other words, cleanings, weedings, liberation, and improvement cuttings), which, depending on what is being removed, may or may not produce forest products. Another set of treatments that alter crown fuels, but are rarely considered as fuel treatments are even-aged regeneration cutting methods such as shelterwoods and clearcuts. Alternative treatments such as shelterwood with reserves or uneven-aged management through individual or group selections are quite effective at altering the spatial arrangement of fuels and overall fuel dynamics over time. Additionally, post-harvest treatments designed for site preparation, fuels reduction, and other such treatments affect surface fuels in a variety of ways.

Manager comment: Spatial context is crucial when designing fuel treatments to reduce the likelihood of crown fire. Nature is messy and not all treatments need spacing between all trees on a given site. Spacing between clumps of trees will effectively minimize sustained crown fires and sometimes the clumpy nature of these stands provides habitat elements as well.

Dry mixed conifer forests, because of their productivity, individual tree species, microsite differences, and a variety of disturbance and fire suppression histories, will tend to favor multiple crown classes—dominant, codominant, intermediate, and suppressed. Dominant crown classes are trees with crowns that extend above the general canopy and receive full light from above. The codominant crown class includes trees with crowns that form the general cover and receive full light from above but little light from the sides. Intermediate crown classes contain trees shorter than the codominants but with crowns that can be ladder fuels to the dominants and codominants. Suppressed trees have crowns entirely below the general level of cover and receive little light from above or the sides and are often overtopped.

Each type of thinning focuses on removing or reducing one or more of these crown classes. Thinning is also used to influence species composition since many species tend to dominate specific canopy layers. Crown thinning removes crowding within the canopy cover. Low thinning removes the lower canopy, leaving large trees on the site. Selection thinning removes dominant trees in favor of smaller trees; therefore, trees above a particular diameter are removed. Free thinning is very flexible and can increase stand diversity by releasing selected trees. It can be used in any of the crown classes for releasing specific tree species such as ponderosa pine (Graham and others 1999) (fig. 8.6).

Regeneration methods, such as shelterwood cutting, seed tree methods, and clearcuts, can remove sufficient overstory biomass to diminish crown fire potential for a period of time (fig. 8.7 and 8.8) (Graham and others 1999). In addition to removal of trees, a variety of surface treatments can be implemented to alter surface fuels, including: grapple piling, prescribed fire, and mastication. Therefore, when the objective is to increase forest resilience in fire-dependent forests, all treatments can be considered fuel treatments.

Often the most successful treatments use a combination of techniques that address crown, ladder, and surface fuels (Stephens and others 2012). Clear objectives are critical

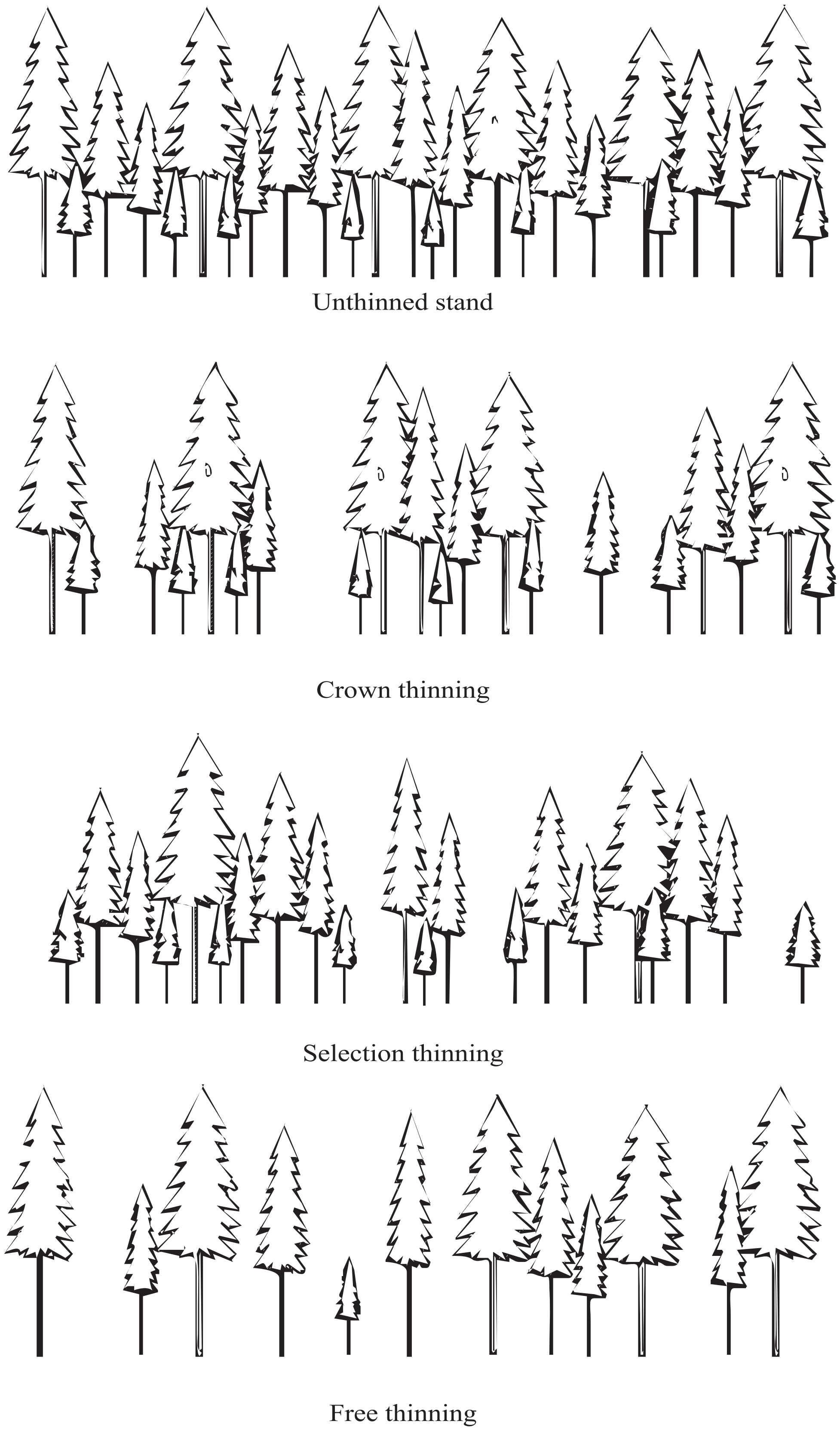


Figure 8.6. A 120-year old conifer stand, with dominant, codominant, intermediate, and suppressed trees receiving a crown, selection, and free thinning (Graham and others 1999).

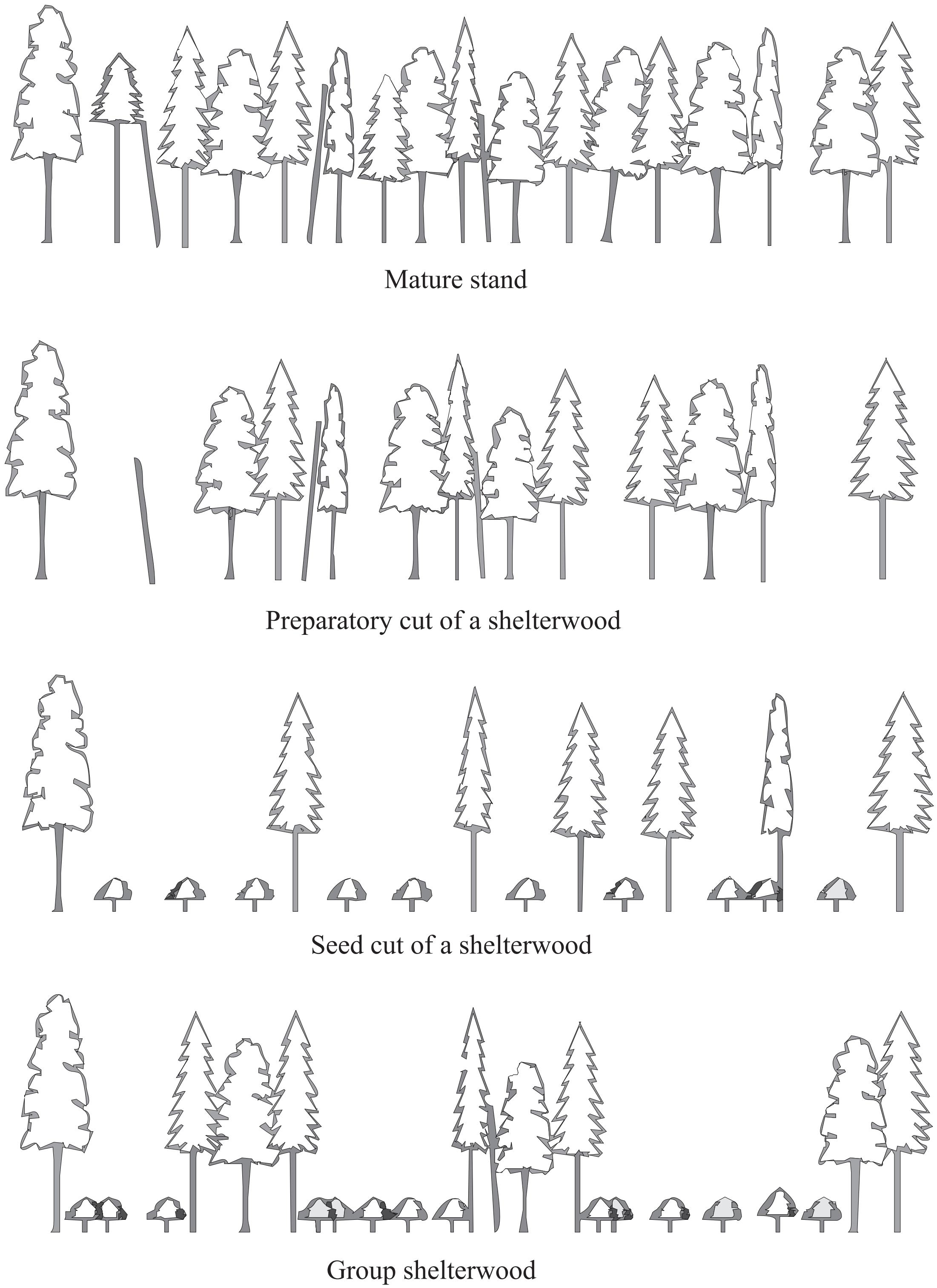


Figure 8.7. Shelterwood regeneration method the preparatory cut is to improve seed production and wind firmness and is typically used before a seed cut. This type of method tends to leave a more homogeneous forest structure with trees often regularly spaced. Another type of method also can be used is a group shelterwood, which tends to create a heterogeneous structure that may address some wildlife habitat attributes (from Graham and others 1999).

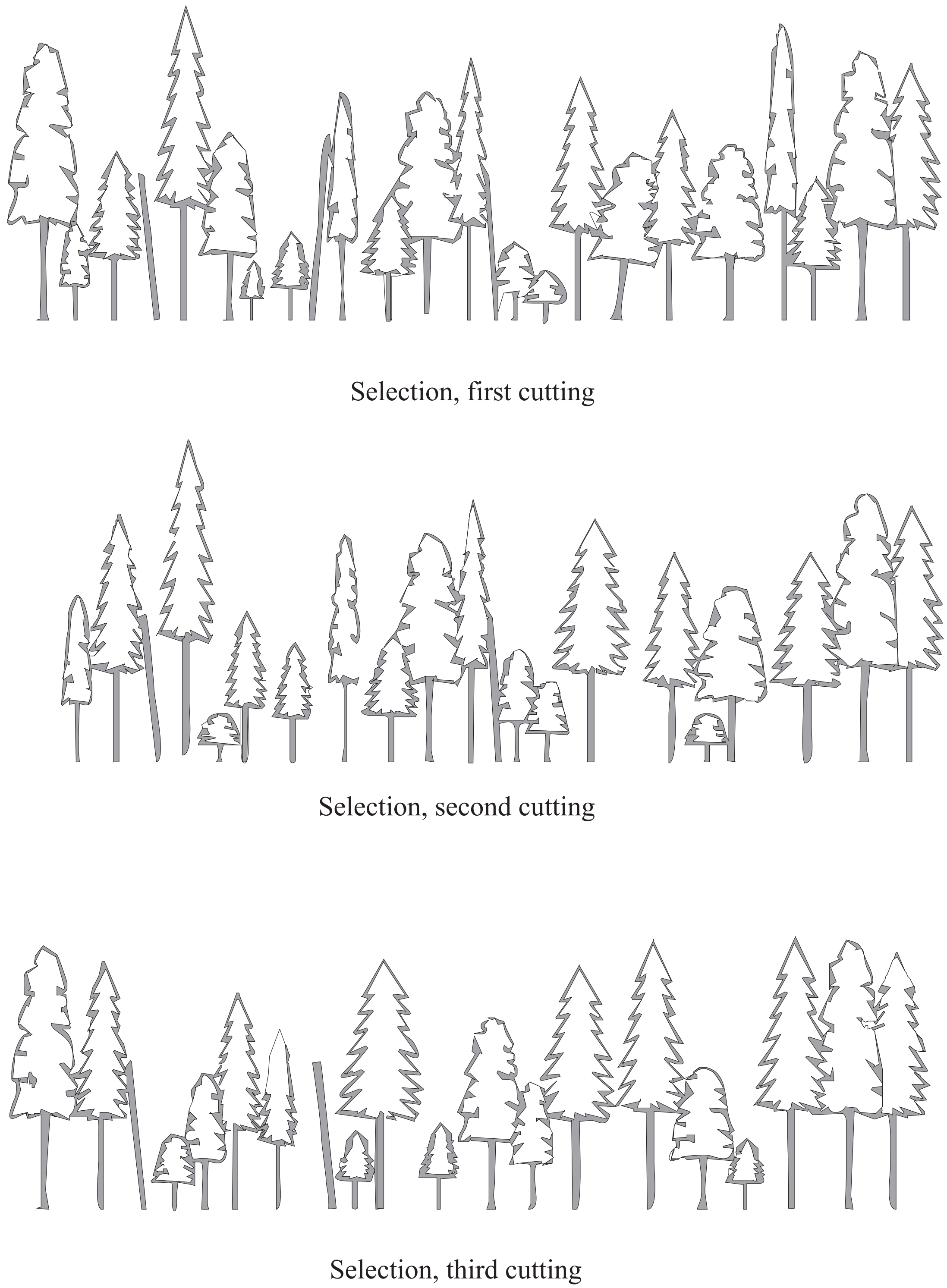


Figure 8.8. An individual tree selection system on a 30-year cutting cycle (Graham and others 1999).

in the implementation of any treatment. Ideally, treatment objectives will include a good description of the desired conditions in the short- and long-term, and an understanding of the time needed to implement the treatments, which in most cases covers years (as was case with the Warm Lake fuel treatments, which took 5 to 10 years to implement; some treatments were incomplete when the wildfires occurred).

Types Of Treatments

Mechanical Methods

Treatments to reduce hazardous fuel accumulations in the forests of the western United States often involve mechanical thinning since these treatments effectively address high levels of fuel continuity (fuels that can support the spread of fire) in high density stands and reduce the complexity of prescribed burning. Mechanical fuel treatments use power tools or heavy equipment to mechanically remove or rearrange trees and shrubs to reduce fire hazard. These treatments can cover numerous steps including: felling, cutting and spreading, skidding (or yarding), and processing (for example, grinding and mastication). Mechanical fuel treatments can alter surface fuels, increase the height to the base of live crowns, and open the canopy by removing trees (Agee and others 2000). There are a number of studies indicating that mechanical fuel treatments that remove small diameter trees can be beneficial for reduction of wildfire hazard including crown fires (Brose and Wade 2002; Graham and others 1999; Pollet and Omi 2002).

Compared to prescribed fire, mechanical fuel treatments allow a higher degree of control for managers and can be used to accomplish objectives related to tree spacing and species composition in residual stands. Undesirable species and tree sizes can be effectively removed through a mechanical felling approach, followed by skidding the felled trees to the roadsides or landings. Smoke management is another factor favoring mechanical fuel treatment. Excessive fuels may be consumed by burning when weather conditions and the biomass moisture content are within specified prescriptions, but burning is often impractical because of the potential negative effects (for example, air quality, risk of escape, damage to soils and residual trees) and time constraints (for example, limited operating periods, short burn windows).

Mechanical fuels reduction treatments can produce forest products such as sawlogs and energy fuels (fig. 8.9). An integrated approach to harvesting both roundwood and biomass, referred to as an integrated harvesting system, is becoming common in fuels reduction thinning treatments. This system uses a set of equipment to produce roundwood products while also removing all sub-merchantable size trees and logging slash for biomass energy (Han and others 2004). The stewardship contracts utilized by the U.S. Department of Agriculture, Forest Service include mechanical fuels reduction thinning units that produce both sawlogs and biomass. Revenues generated from selling these products may partially or fully cover the expenses of other fuel treatment units that produce no sawlogs. Other mechanical fuel treatments include pre-commercial thinnings (do not produce sawlogs), hand thinning (lop and scatter), and mastication.

There are various equipment options and systems for mechanical fuel treatments, and it is important to understand the capability and limitations for each piece of equipment and system in accomplishing fuels management objectives. Timber harvesting equipment and systems are commonly used in fuels reduction thinning projects because they were originally designed to handle felling, extraction, and processing of trees. Machine types and thinning methods used in mechanical fuel treatment directly affect the fuel conditions (surface fuels, ladder fuels, and canopy bulk density) resulting from treatment and the vegetation responses after treatment. Therefore, fuels managers need to

Figure 8.9. Skidder extracting whole trees to a landing where trees are processed into sawlogs or biomass for energy production.

specify equipment type, size and how it should function in its operation. Selecting an optimal set of equipment or system that meets treatment needs at low costs and minimal environmental impacts requires a high level of knowledge on equipment options for mechanical fuel treatments.

The biomass generated from mechanical fuel treatments can be left on site, removed to landings for further treatments (pile or pile and burn), or processed as sawlogs and energy fuels. The decision of whether biomass will be left on the site or removed will directly affect the equipment selection decision, which determines the outcome of the overall fuel treatment. In this guide, we include five major options that are used to treat hazardous fuels. Two of these options include leaving biomass on site: mastication and hand thinning. The other three options involve biomass removal and include traditional forest harvesting systems: ground-based, cable, and helicopter. Each system will have different treatment costs and result in different outcomes, effectiveness, and impacts on other ecological values. This section details the five major options for mechanical fuel treatment.

Retain Biomass

Mastication

Mastication affects fire behavior by altering the orientation, depth, distribution, and size of fuels through grinding and shredding shrubs, standing small trees, and downed woody material, and leaving a mat of shredded wood on the soil surface (Battaglia and others 2010; Glitzenstein and others 2006; Kane and others 2009) (fig. 8.10 and 8.11).

Figure 8.10. Horizontal drum masticator effectively masticating a blanket of shrubs.

Figure 8.11. Rotary head masticator (boom-mounted) effectively shredding single trees.

Mastication treatments decrease fire hazard by raising canopy base height of standing trees and maintaining the masticated materials close to the ground (Battaglia and others 2010; Kreye and others 2011). Nutrients remain on site and soil compaction can be minimal if the equipment travels on the masticated materials with minimal to no repeated traffic on the same path. Sedimentation or soil erosion following rain or snowmelt from areas treated by mastication is of less concern because of the thick layer of mulched wood left on site. Mastication is often considered when thick shrubs or dense small diameter trees are a prevalent fuel type in a high fire hazard area or fuels have accumulated from thinning. Mastication treatment costs can be high, but it is a viable, effective alternative for fire hazard reduction when the treatment area cannot be burned, removal of excessive fuels is not economical, or impacts on soil and sedimentation are of concern.

The objective for using mastication is to favor rapid decomposition, and, as mentioned, it is an alternative treatment when no other options will meet the objectives. The following elements deserve consideration prior to using mastication. Factors that influence decomposition include temperature, moisture, oxygen availability, substrate quality, size, and decomposing organisms (Harmon and others 1986). Wood decaying fungi have an optimum temperature of 55-85 °F (15 to 30 °C) and optimal moisture will vary from 30 to 240 percent moisture content depending on the organisms. The species and state of decay targeted for decomposition, along with the wood substrate, are also important. The proportion of bark, sapwood, and heartwood will influence decay rate; heartwood takes more time to decay than sapwood.

The type of plant also influences the decay rate; shrubs tend to decay before conifers (Enríquez and others 1993). True firs decompose quicker than Douglas-fir, western larch, and western redcedar, which are more decay resistant. Piece size is also important; if the material is ground too fine it may insulate the ground and the pieces may dry too quickly, thus disfavoring decomposition. Also, when burned, small pieces tend to be dispersed creating fire brands that may ignite outside of the masticated area. Depending on the material being masticated, it may be preferable to create chunks or larger shredded material rather than small pieces (aim for leaving material >3" when opportunities exist). This accomplishes a couple objectives: it disfavors the increase in fine fuels, and larger material will contain higher moisture than small material and longer logs. In addition, larger pieces may address wildlife habitat elements. Treatments should avoid a homogeneous mastication bed, leaving areas with no masticated material and isolating masticated material with other site preparation or slash treatment methods. Not every square foot of the area needs to be treated, so it is important to leave a diversity of soil substrates. Mastication increases fine fuels and potentially creates a deep organic bed favoring high soil temperatures and long-term smoldering during wildfires; thus, evaluation of the short-term versus the long-term benefits, as well as the do nothing alternative, deserves consideration (Busse and others 2005; Reiner and others 2009). Prescribed burning of masticated material will require different burning parameters than typically apply and may be difficult to implement because of the risk of smoldering. Other options such as hand slashing and grapple piling may need some consideration. For further discussion concerning burning masticated material refer to unique situations in chapter 9, prescribed fire.

Hand thinning (lop and scatter)

Hand thinning, often referred as lop and scatter, is used to reduce the connectivity of vertical and horizontal fuels by felling trees, cutting them into lengths, and spreading severed woody materials over the ground (flowchart 8.2, fig. 8.12). This method is often considered when it is impractical to remove excessive fuels (in other words, trees and shrubs) from the site due to lack of wood markets and road access. Mastication

Figure 8.12. Trees were cut to lengths and left on site for natural decomposition.

may be used for this situation, but steep slopes (>30 percent) make it difficult to use masticators. A lop and scatter approach may also be appropriate when there is a small amount of non-merchantable, small-diameter trees that need to be treated to accomplish fire hazard reduction objectives. This method is also used as a pretreatment for pile and burn or prescribed under-burning. Nutrients from cut trees remain on site, which may be an important factor for some nutrient-lacking sites or vegetation types demanding a high level of nutrient recycling. Large woody debris and limb/tops also create favorable environments for wildlife and microorganisms. To enhance decomposition, severed materials need to be in contact with the ground, the location where the most active decomposition occurs. Nevertheless, natural decomposition of fuels left on the soil surface may take several years (Carlton and Pickford 1982) and untreated residue may result in undesirable fire behavior (Stephens 1998; van Wagtendonk 1996). To address this issue, pile and burn is often combined with a hand thinning method. Chainsaws are commonly used to fell shrubs and trees and cut them into small pieces to be scattered throughout the treated stand.

Remove Biomass

Fuels reduction thinning using ground-based systems

Treatments to reduce hazardous fuel accumulations in forests frequently involve mechanical thinnings that retain larger trees and thin dense stands, effectively reducing fuels and allowing prescribed burning (Fiedler and others 2003; Graham and others 1999; Pollet and Omi 2002) (flowchart 3). In the context of fuels reduction, a whole tree harvesting (WT) method is often favored by managers since the method effectively removes limbs and branches as well as boles at the time of thinning, leading to a minimal increase in surface fuel loading (fig. 8.13). Another typical harvesting option for fuel treatments is a cut-to-length (CTL) method that processes trees to log length at the stump (fig. 8.14).

Figure 8.13. Feller-buncher felling and creating bunches of whole trees for skidding.

Figure 8.14. Harvester felling and processing trees at the stump, leaving limbs and tops on site.

The processed logs are extracted using a forwarder, leaving all branches and treetops on site. This approach reduces problems related to nutrient retention, but short-term surface fuel concerns remain because of limbs and tops that are often concentrated on the operating trail to minimize soil disturbance from log extraction activities. Roundwood products (for example, sawlogs and pulp wood) and hog fuel for energy production may be harvested from a WT thinning, but it is common to produce roundwood products only in a CTL thinning. While production rates and costs for these two systems are comparable, impacts to on-site productivity and residual trees can differ significantly (Adebayo and others 2007; Han and others 2009; Han Kellogg 2000; Lanford and Stokes 1995, 1996).

Woody biomass generated from thinning may be piled at landings for decomposition or burning. More commonly, forest products such as sawlogs and pulpwood are recovered from the trees removed from thinning treatments and sold to local markets to generate revenues. Integrated harvesting strategies that combine mechanical thinning and biomass harvesting are often preferred over harvesting and burning treatments because of smoke, risks of fire escape, and residual tree damage. An integrated harvesting system uses a set of equipment to produce roundwood products and remove all sub-merchantable sized trees and logging slash. Compared to typical harvesting systems that only remove merchantable materials, an integrated harvesting system often requires a chipper or grinder that converts sub-merchantable size trees and logging slash into materials of uniform size that can be handled, transported, and/or stored efficiently (Lambert and Howard 1990).

Fuels reduction thinning using skyline yarding systems

Because of the effects of pre-heating, fires spread rapidly on steep slopes (Rothermel 1983) and greater concerns over high levels of fuel loading exist on steep slopes than on gentle slopes. However, fuels reduction thinning on steep ground is more difficult and costly to implement than doing similar work on flat terrain. Cable yarding systems can be used to reduce excessive fuels on steep slopes (>35 percent) not operable using ground-based skidding machines. In cable yarding, logs or whole trees are partially or fully suspended to the skyline and pulled to the landing or roadside areas (fig. 8.15). Fuels reduction thinning using skyline yarding systems utilizes the same methods as cable logging: a yarder is set up at a landing or road to yard whole trees or logs from the stand. For the purpose of reducing fuels in the forest, sub-merchantable size trees as well as large, merchantable logs/trees may be removed from the stand.

A new approach for skyline operations is the use of yoaders (yarding equipment with no guylines) to remove small-diameter trees for short yarding distances on steep slopes and unstable soils. Yoaders have been shown to be highly productive, comparable with conventional skyline yarders due to reduced skyline road/landing changing times (up to 44 percent reduction with no guylines) and short yarding distances (<600 ft) (Largo and Han 2004). Yoaders may be effectively used in steep and remote areas since this yarder can move into a harvesting unit without roads or skid trails. The use of yoaders in fuels reduction thinning is a relatively new concept, but has been considered in many places (fig. 8.16).

Fuels reduction thinning using helicopter yarding

Helicopter yarding is often considered when environmental concerns are high, road access is limited, and work needs to be done quickly (flowchart 8.3, fig. 8.17). Helicopter yarding distance is typically longer than ground-based and skyline yarding systems, ranging from 2500 to 5000 ft (Studier and Binkley 1974). This long yarding distance requires fewer roads to be built or maintained to implement fuels reduction thinning. It should be noted that roads are still needed to access landing locations.

Figure 8.15. Yarder extracting whole trees or processed logs on steep ground (>35 percent slope).

Figure 8.16. An excavator-based yoader performing a fuel reduction thinning in northern Idaho.

Figure 8.17. Vertol helicopter (10,000 lbs maximum external load) yarding in a fuel reduction thinning.

Yarding productivity using helicopters is high. For example, consider a small-diameter tree thinning operation in Oregon: the net production estimate for helicopter yarding using a Sikorsky S58-T was 4.71 MBF per hour compared to only 1.65 MBF per hour for the cable yarding system (Born 1995). The major drawbacks with helicopter yarding are the high fixed costs (for example, machine prices) and variable costs (for example, fuel and labor). For this reason, helicopter yarding is not a favorable option for small treatment areas (<500 acres): helicopter yarding may be financially justified only for a large contract to minimize fixed costs.

Selection of Equipment for Mechanical Fuel Treatment: A Flowchart Approach

Selecting the appropriate equipment for a mechanical fuel treatment is a complicated task because a final decision on equipment selection should effectively address: (1) requirements or objectives of mechanical fuel treatments, (2) work conditions under which treatment operations are implemented, and (3) efficient use of a limited budget. It is important to recognize critical variables that override other constraints and requirements. For example, certain sites that are identified for a mechanical treatment require that biomass be left on site because of nutrient retention concerns. This constraint eliminates any equipment options commonly used to extract forest biomass. Further, within the set of equipment options that leave biomass on site, there are a wide range of equipment options that may work only for certain terrain and stand conditions. This requires additional steps to select the best equipment option in terms of type and size for a given mechanical fuel treatment task.

Equipment Selection for Mechanical Applications

A systematic approach using a flow chart is helpful to identify the right equipment that addresses requirements and constraints for a given fuel treatment task. The flow chart approach requires ranking the important factors (in other words, treatment requirements and operational constraints) that influence equipment selection decisions. Highly ranked variables have a greater influence on equipment selection than those listed as low priority items. However, in some cases, an overriding issue may specify that a certain type or size of machine be used for the job, or eliminate most equipment options that do not meet certain specific needs.

Forest managers need to decide whether hazardous fuels are to be removed or treated and left on site. A decision to leave biomass on site eliminates any equipment options that are used to harvest biomass. This decision also determines potential forest products that may be recovered from mechanical fuel treatments. Once a decision to leave or remove biomass is made, terrain becomes the next consideration as equipment operability is limited by ground slope. By applying decisions on biomass removal or retention and ground slopes, there are five major categories of mechanical fuel treatment systems. An overview of this general approach is summarized in figure 8.18.

Once the decision has been narrowed down to one of these five options (mastication, hand thinning, ground-based system, cable system, or helicopter system), the next step is to work through the steps for each option to specify an equipment option (fig. 8.19). The previous sections of this document provided general descriptions of those five options in regards to applicability to meet treatment needs and operational advantages and limitations of each option. It is important to note that an initial decision to select one of those five options may change to another option because of important constraints or requirements. For example, a ground-based system may be selected because hazardous fuels are to be removed from the site and ground slopes are gentle (<30 percent). However, it should be noted that soil impacts from ground-skidding activities are a major concern. In this case, either a skyline or helicopter system may be selected to minimize soil impacts. This case is presented using arrows in the flow chart (fig. 8.20). Alternatively, ground skidding may be delayed until the dry season when soil moisture content is low (<15 percent; Han and others 2006).

Within the set of equipment options for leaving biomass on site, mastication equipment can be used only on gentle terrain: running a masticator on steep ground may create operator safety issues, excessive soil impacts, and increase costs (fig. 8.21). A thick blanket of shrubs that cause high fire hazard favors a mastication treatment over hand thinning. Mastication also leaves small particles of woody materials, which may be favored when leaving untreated activity fuels on site is not allowed. Masticators need to be further specified to effectively reflect work conditions and treatment needs. Hand thinning (lop and scatter) effectively targets single or multiple stems of trees and shrubs, leaving processed materials (cut into several pieces) on the ground. These materials are retained on site for decomposition or burned if needed. As an alternative to these two options, trees may be felled, chipped, or blown back into the stand.

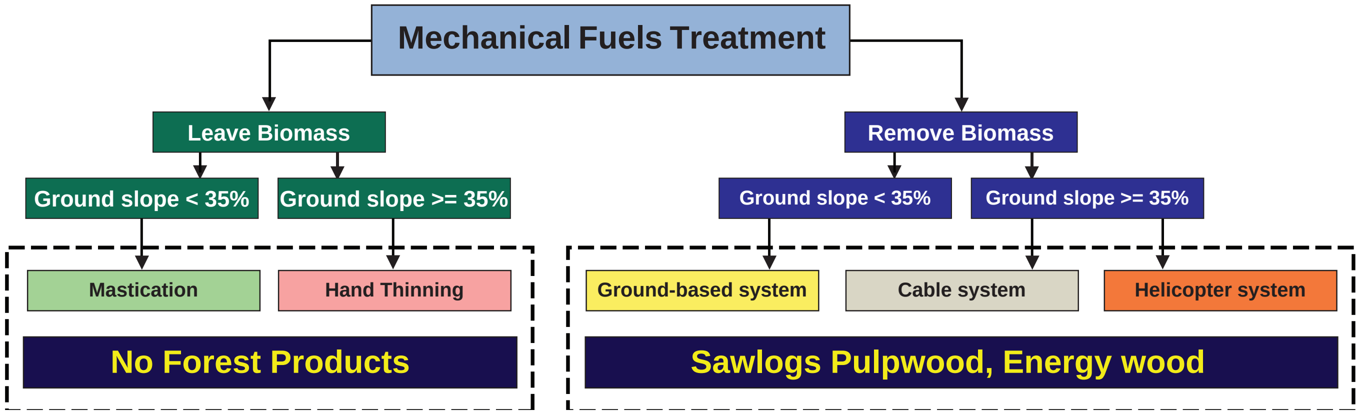


Figure 8.18. An overview of selecting a mechanical fuels treatment option and potential forest byproducts using two criteria: biomass treatment and ground slopes.

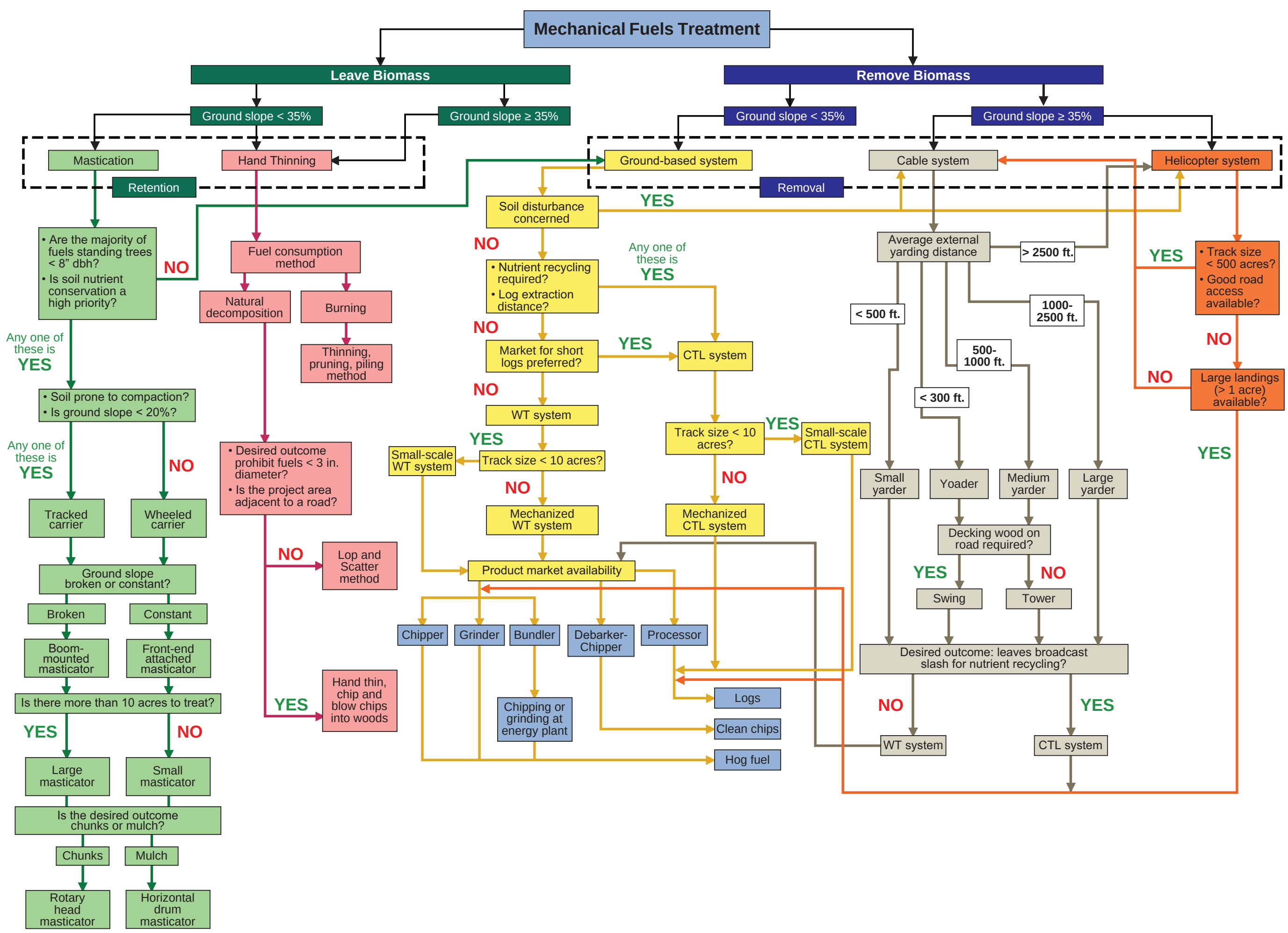


Figure 8.19. This flow chart illustrates the complexity associated with identifying the appropriate mechanical treatment.

Equipment options and methods for retaining woody biomass on the ground

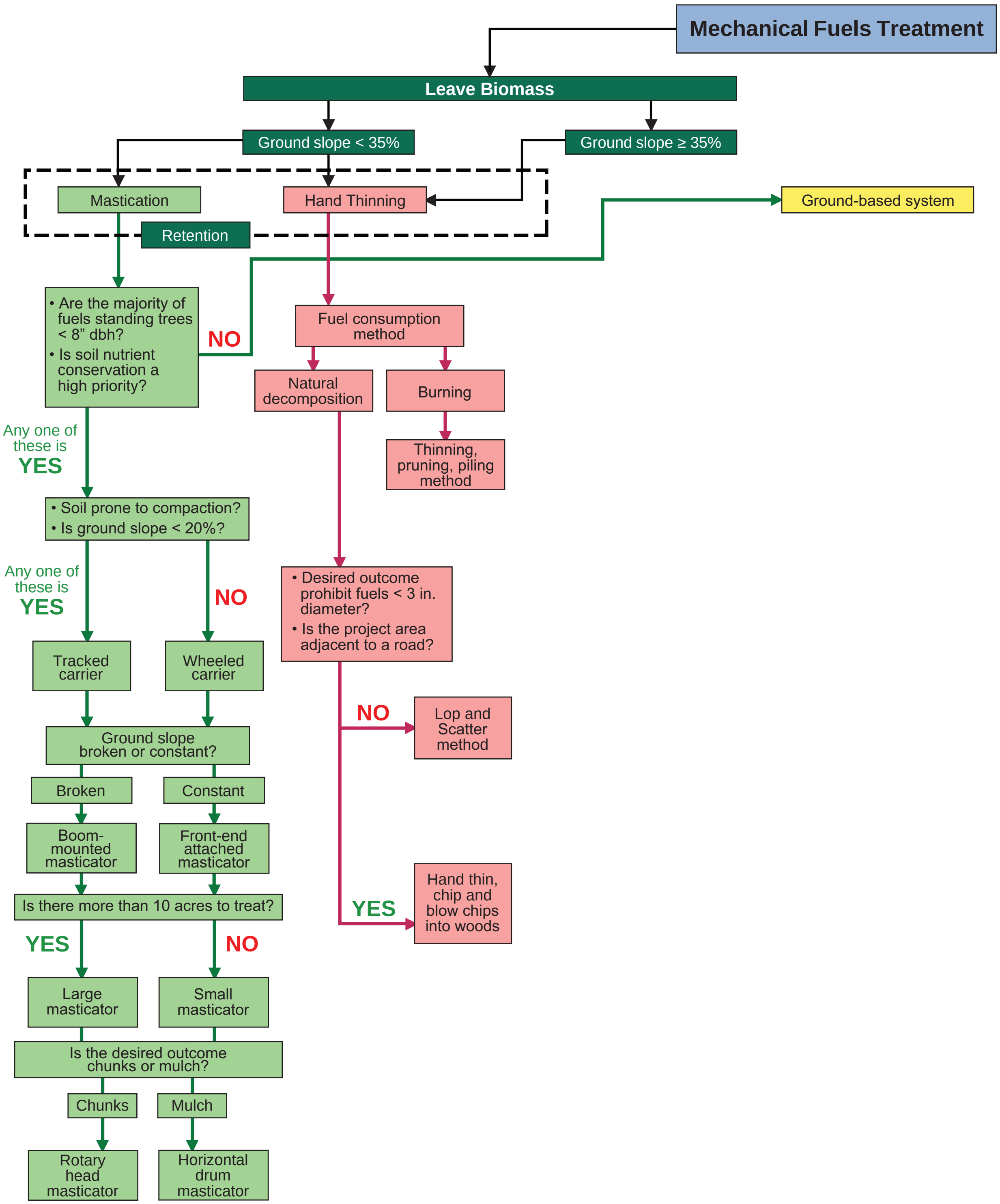


Figure 8.20. A flow chart to select a mechanical fuel treatment option when leaving biomass on the site.

Equipment options and methods for removing woody biomass and product recovery

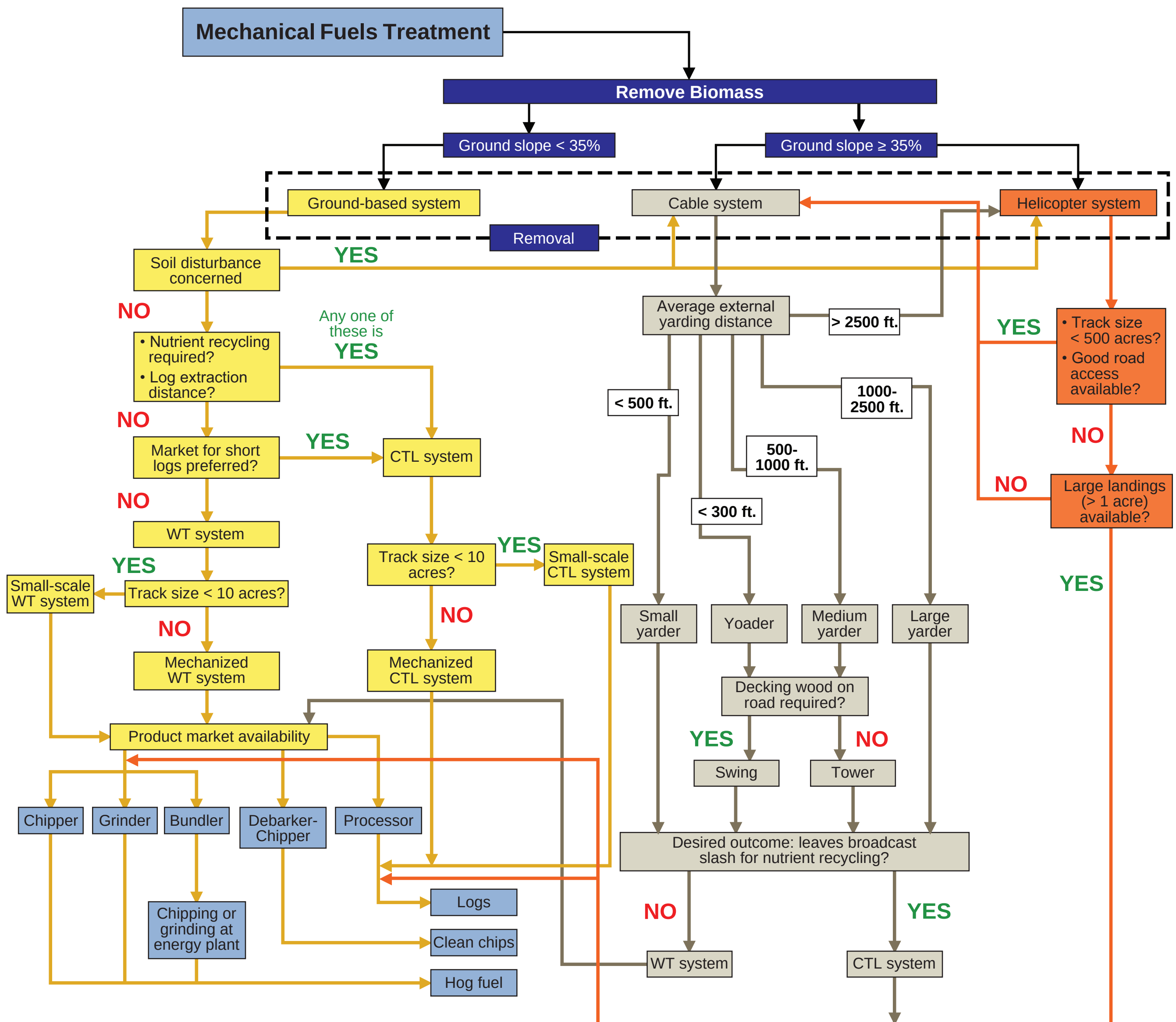


Figure 8.21. A flow chart to select a mechanical fuel treatment option when removing biomass.

Treatment or utilization of biomass collected at a landing or roadside needs to be carefully evaluated when biomass removal is required. This directly affects equipment selection decisions. While terrain has a major impact on equipment selection for biomass removal, decisions on removing whole trees or bole-wood (in other words, main stem wood) only determines tree processing location (in other words, stump or landing) and the equipment to be used. Whole tree removal may require a chipper or a grinder at the landing to process sub-merchantable trees and forest residues left from sawlog processing. Removing only bole-wood generally does not require a grinder or a chipper at the landing because limbs and tops are retained. Surface fuel treatments such as prescribed burning or mastication may be necessary to address the short-term increase in fire hazard.

Chemical Control

Marshall and others (2008) provide an excellent discussion of herbicide use for fuels management in loblolly pine forests in the southern United States. Rather than repeating much of what they suggest, we summarize key points to consider when using a chemical agent to treat fuels, and we point to additional considerations for dry mixed conifer forests. There are a series of factors to consider when determining whether herbicides can be effective at treating fuels.

Factor 1: Current condition. Herbicides become a practical option when one or more of the following conditions occur: (1) overstory trees are able to respond to, release, and fill canopy openings after targeted vegetation is killed using herbicides, (2) fast growing or sprouting vegetation must be treated at regular intervals to increase the longevity of a fuel treatment, and (3) herbicides are the only effective way to remove invasive plant species.

Factor 2: Terrain and soils. Similar to mechanical treatments, herbicides have to be applied using some type of equipment. Therefore, slopes should be accessible mechanically. Also, if steep slopes surround a relatively gentle sloped treatment area, then the treated areas may be of insufficient size or juxtaposition to allow effective or viable fuel treatments. Soils are also critical: if they are too sandy, they drain too quickly, limiting the effectiveness of the herbicide in killing the roots. In contrast, clayey and loamy soils can quickly immobilize soil-active herbicide, making it an impractical option.

Factor 3: Size and type of vegetation. Herbicides become more impractical with large and tall vegetation. If the vegetation is low to the ground then the next option is to determine if there is a good match between the herbicide and the vegetation targeted for removal. Herbicides used for shrub control include 2,4-D, Glyphosate, imazapyr, picloram and triclopyr. To control grasses and forbs, atrizine, 2,4-D, sulfometuron, and hexazinone are suggested (Peachey 2011).

Factor 4: Effects on fuel. Herbicides do not kill vegetation immediately. Depending on the target vegetation, it may take a few months to kill leaves and needles, and up to 1–2 years for branches, depending on their size. In addition, herbicides change the fuel matrix from live to dead fuels, which may actually increase susceptibility to fire. A considerable amount of dead fuel is contributed to the forest floor; yet much is still aerial and is not in contact with the forest floor, meaning the dead fuel may not decompose or break down quickly. Therefore, using herbicides alone may not be a viable option and most likely should be used in combination with prescribed fire or another form of biomass removal (Gagnon and Jack 2004).

Factor 5: Cost. The cost of herbicide applications depends on the acreage being treated, the mode of application, and the type and amount of herbicide. Although an exact estimate depends on many factors, in general, cost per acre increases for manual application and decreases for aerial applications. However, this relation is dictated by size of the treated area: small areas may be more cost effective using manual application versus aerial application.

In the dry mixed conifer forests this may be a viable option in highly dense shrub areas that are too large for a prescribed fire to kill or the burning windows are such that prescribed fire is so limited that it is difficult to implement. Herbicide applications may also be the best option in areas where there is insufficient value to justify a mechanical treatment. Using a two treatment approach—herbicide followed by prescribed fire—may be a viable option in treating more difficult fuel beds that are common within these forest types. A good source of additional information concerning herbicide use is the *Pacific Northwest Weed Management Handbook* (Peachey 2011).

Biological Control/Grazing

Biological control of surface fuels through targeted grazing is another alternative that may be effective under the right conditions. The feasibility of biological control depends on whether the appropriate livestock are available (goats, sheep, cattle) for the particular species of fuel that needs to be controlled. Also personnel have to be available with the proper expertise to herd and manage the livestock. Finally, the livestock have to be on site when the plant's phenological stage is the most conducive to control. When these conditions are met, biological control can remove biomass, diminish subsequent growth, and reduce seed input (Diamond and others 2009).

Options: Successful implementation is a function of a clear understanding of the target vegetation (fuel) and post-treatment outcome and the appropriate type of livestock and species for meeting the particular target (Launchbaugh and Walker 2006). The most effective way to combat invasive species is to select the species that consumes the targeted plant for control (Burritt and Frost 2006). It is not necessary to select only one species; multi-species grazing has some advantages. Multiple species with different dietary preferences can provide more even utilization of all forage species, avoiding an advantage to one plant species or class of species. Burritt and Frost (2006) illustrated a system in which sheep were combined with cattle grazing to control leafy spurge. The sheep are used initially to consume the flower heads (when spurge is in the yellow bract stage), and this removed the seed production. Cattle were than released during the normal grazing season. In addition, there are a variety of other factors to consider such as animal age, body condition, and sex of the animal, which can affect diet selection and foraging behavior. For example, goats with worn teeth tend to avoid grasses and choose tender-leaved shrubs versus goats with unworn incisors (Burritt and Frost 2006) (please refer to Targeted Grazing Handbook for further information).

There are four primary species that can be used in targeted grazing: cattle, horses, sheep, and goats. In general, cattle and horses are grazers and primarily consume grass. Cattle, because of size and mouth design, are better adapted to grazing than browsing (Burritt and Frost 2006). Also, the muzzles of cattle prevent them from selecting among plants or specific plant parts. However, cattle also have a digestive system that allows consumption of lower quality roughage. This gives them an advantage over sheep or goats, because they consume fibrous and abundant herbaceous vegetation like dormant grasses. Sheep are intermediate feeders with their narrow muzzle and large rumen relative to body mass, which allows them to graze selectively, but also tolerate substantial fiber content. Sheep have small mouths, which allow them to graze close to the ground and select specific plant parts such as small leaves or buds (Burritt and Frost 2006). This attribute gives them an advantage over cattle because they can strip leaves or flowers from stems. Sheep generally favor forb consumption; however, they also consume grass when they are succulent and other forage is unavailable. Sheep are sure-footed and well suited for rough topography and will graze steeper terrain than cattle; they tend to avoid marshy areas. Goats are browsers and can eat many types of unwanted vegetation. They also produce marketable products (goat meat and milk) (Hart 2001). Goats are resistant to many plant toxins and non-nutritive factors. Goats prefer browse (73 percent) to grasses (23 percent) and some forbs (4 percent) (McMahan 1964). Goats can restore cycling of plant nutrients, which are sequestered by woody plants. Goats prefer to consume seeding stems, reducing the spread and perpetuation of weeds by seed. Targeted grazing with goats may increase treatment longevity after mechanical or prescribed fire by maintaining low levels of brush.

Challenges: As with any fuel treatment method, a successful target grazing prescription requires substantial preparation and a level of experience and knowledge. Targeted grazing involves pairing the specific species and breed of livestock during a particular season, for a predetermined duration, and at a sufficient intensity to accomplish the defined vegetation or landscape management goals. Substantial knowledge of the ecology and life cycle of plants, a thorough knowledge of breeds and species available, and animal management skills are required. An established monitoring plan is recommended so that the grazing prescription is adapted based on short- and long-term results (Sharrow and Seefeldt 2006). Also, patience and commitment is required because it may be three years of implementation before noticeable differences are detected. If interested in pursuing this method for fuels management we recommend visiting the web site “Targeted grazing: a natural approach to vegetation and management handbook (2006).” The internet link and full citation is provided under the Further Reading section at the end of this chapter. Direct contact with the authors may also provide up to date information since the publication of this resource.

Conclusion

There are a variety of ways to treat forest fuels through mechanical means, prescribed fire, grazing, and chemicals. In many cases, mechanical treatments followed by prescribed fire or other mechanical techniques such as mastication, grapple piling, or other combinations of treatments have proven to be the most effective. The main point is not to limit what treatment techniques are used but to select the best treatment or combination that meets the objective.

Further Reading

Launchbaugh, K. L.; Walker, J. W.; Daines, R. L., eds. 2006. Targeted grazing: a natural approach to vegetation management and landscape enhancement. Centennial, CO: American Sheep Industry Association, A. Peischel and D. D. Henry Jr. 199 p. (Provides a wealth of knowledge concerning the use of targeted grazing to meet vegetation management goals. There are five sections in this synthesis. Principles and overview provide a primer on targeted grazing, animal behavior principles and practices, understanding plant response to grazing and other basic and valuable information. Section 2 focuses on objective specific information and how targeted grazing can be applied. Section 3 provides grazing and browsing guidelines for invasive plants. Section 4 discussing how to develop contracts for grazing and browsing and other administrative aspects in applying targeted grazing. The fifth section provides a variety of other resources for targeted grazing.)

Peachey, Ed, ed. 2011. Pacific Northwest weed management handbook. Corvallis, OR: Pacific Northwest Extension. 464 p. (Provides detailed information concerning herbicide use.)

Chapter 9

Prescribed Fire

Chapter Rationale

Fire is an important process that has played a major role in shaping the evolution of dry mixed conifer forests. This has led many to believe that fire is also the best option for treating fuels in these systems. However, the use of fire is never straightforward and always contains elements of uncertainty and complexity. Therefore, the following questions were used to organize the information provided in this chapter.

- Prescribed fire has an element of uncertainty and risk; thus there are several steps that are required prior to ignition. Is there a way we can communicate these steps so that other disciplines and stakeholders can better understand this uncertainty and risk?
- Mentoring is an important aspect of passing prescribed fire skills and knowledge from one generation of fire practitioners to another. Is there information that can be provided to aid in mentoring?
- Are there unique situations where unique fire parameters need some consideration?

Introduction

Prescribed fire can be used to achieve a variety of objectives. It can be used to reduce hazardous fuels, dispose of logging debris, prepare sites for natural or artificial regeneration, improve wildlife habitat, manage competing vegetation, control insects and disease, and improve forage. Prescribed fire can also be used to enhance aesthetics, improve access, and restore or maintain forest structures, species, and function within fire-dependent forests. Good fire practitioners combine science, decision support tools (for example, fire behavior models), and monitoring with their own experience and instinctive knowledge (art) when applying fire. Because the critical elements vary considerably based on the location and conditions, fire practitioners we interviewed suggested not to provide specific parameters for the use of prescribed fire. Each site is unique in fuels, on-site conditions, and predicted fire behavior; therefore, what works in one place may not work in another location. However, we also want to illustrate the complexity of prescribed fire and the steps each manager takes to promote success. Consequently, we have included the key elements of a burn plan and an associated complexity analysis. Even with the maximum amount of care and time invested in planning a prescribed fire, there is always an element of uncertainty. Within this context, we also summarize analysis of lessons learned from previous escaped fires.

The use and effectiveness of prescribed fire depends on objectives, current conditions, and desired post-fire outcomes. Prescribed fire alone tends to work best when used for maintaining resilient forest conditions such as open park-like stands (where appropriate), which have had either mechanical treatments or treated with multiple prescribed fires (Busse and others 2009). However, when current forest conditions contain ladder fuels, non-resilient species compositions, and other factors that complicate prescribed fire, a combination of mechanical treatments and fire may be the most desirable option

(Busse and others 2009; Schwilk and others 2009). In harvested sites with complex surface fuels and fire resistant species, prescribed fire is often the preferred treatment. However, multiple prescribed fires may be needed to produce desired outcomes (Busse and others 2009). Therefore, combining prescribed fire with other tools such as commercial harvesting and mastication may be more successful at meeting desired outcomes (Agee and Lehmkuhl 2009; Jain and others 2008; Schwilk and others 2009; Stephens and others 2012).

Prescribed fire can be an effective and, in some cases, an economically viable option; nevertheless, implementing a prescribed fire is complicated. There are several steps fire managers execute before conducting a prescribed fire. The process is far more complex than using other treatment techniques, because of unavoidable risks and the ever present potential for an escape. Experienced fire practitioners use considerable finesse when planning and implementing a prescribed fire. Fires require a commitment to monitoring and adaptation of prescriptions based on experience.

Manager comment: Prescribed fires can exceed mechanical treatments in implementation costs and at times are not practical due to vegetative conditions, proximity to values, and smoke impacts.

Manager comment: Historical data, especially relating to live fuel moistures, is critical. The national live fuel moisture database and the trend data collected on site can be used to plan and implement a burn.

Manager comment: Prescribed fire reflects many of the natural ecological processes that these systems need, even at the smallest scale. The processes of combustion, fuel consumption, and nutrient cycling are beneficial to fire dependent forests. For fire dependent ecosystems, these processes are critical even if the actual fire effects on the vegetation (in other words, desired conditions) are not necessarily leading to natural patterns or compositions (in other words, artificial fuel breaks).

Developing a Burn Plan

The Interagency Prescribed Fire Planning and Implementation Procedures Guide (Prescribed Fire Guide 2008) outlines 21 elements for developing and implementing a burn plan (table 9.1). Unlike mechanical treatments, fire contains more uncertainty in implementation. Weather can change, creating conditions that may lead to an escape, produce smoke, and pose risks to human and resource safety. The agency administrator, line officer, or decision-maker in charge of a fire is aware of all elements associated with a particular prescribed fire prior to making a decision. Similarly, part of preparing for any prescribed fire is to ensure that hazards and risks are identified and mitigation for such events is planned. Accordingly, a series of steps have been identified to ensure that these aspects are carefully considered (table 9.1). Although each step is critical when developing and implementing a burn plan, many are self-explanatory, such as the description of the signature page, prescription of the area, and scheduling. Therefore, we focus our discussion only on the steps that managers referred to during interviews.

Manager comment: When developing a burn plan, it needs to be specific enough to successfully implement the burn but allow enough flexibility that the project is not pushed into a corner, losing sight of the scope and purpose of the burn. It's is a matter of finding the right balance.

Table 9.1. There are 21 elements that need to be considered and documented in preparing and implementing a prescribed fire (Rx) plan (Prescribe Fire Guide 2008).

Element	Name of element	Included documentation	Description of documentation
1	Signature page	Signatures of responsible officials	Project name, signatures, and complexity rating, and signed amendments.
2	Go/NO-GO checklist	Administrative checklist	Should be completed prior to implementing prescribed fire.
		Prescribed fire checklist	Prior to ignition operations, the burn boss will complete and sign and will be revisited each day prior to ignition.
3	Complexity analysis	Process used to identify risks and uncertainties related to Rx activities	Includes evaluation on risk, potential consequences, and technical difficulty.
4	Description of area	Physical description	Location, size topography, project boundary.
		Vegetation and fuels description	Includes within project boundary but also adjacent to the boundary for potential escaped fire threat.
		Identify and describe unique features and resources	Identify special features, hazards, regulations, issues, and constraints. Vicinity map and project maps with title, preparer, date, north arrow, scale and legend.
5	Objectives	Resources and fire objectives	Clear, concise, and measureable and quantifiable prescription elements
6	Funding	Funding source and cost	The cost may be broad or itemized by phase.
7	Prescription	Measurable criteria that define range of conditions during ignition and be held as a prescribed fire	Low and high limits for environment and fire behavior to meet objectives concerning: resources, smoke, and control.
8	Scheduling	What is the time frame in which the prescribed fire will occur	Include general ignition time frame (time of day, duration of ignition), season, and no burn days.
9	Pre-burn considerations and weather	Document all on and off-site tasks to be addressed prior to implementation	Include information on: clearances, mitigation actions, line building, holding points, etc; fuel sampling and weather data needed and frequency during burning for weather measurements; and organizations and landowners to notify.
10	Briefing	All personal are briefed at beginning of each operational period. Checklists are provided to ensure all subjects are covered	To ensure safety, objectives, and operations are clearly understood including contingency plans and assignments.
11	Organization and equipment	Determined by complexity of the fire to safely achieve Rx objectives	Includes implementation organization, Iorganizational chart and responsibilities and equipment needed.
12	Communication	Communication plan	Identify and assign command, tactical, and air operations if needed and contact information.
13	Public & personnel safety, medical	Describe safety provisions for public and personnel conducting the prescribed fire	This includes protective clothing, safety hazards, measures take to reduce safety hazards, safety plan, evacuation methods and emergency facilities and any associated job hazard analysis specific to the Rx.
14	Test fire	Verifies prescribed fire behavior characteristic and whether it will meet objectives and predicted smoke dispersion	Test must be ignited in a representative location and an area that can easily be controlled.

(con.)

Table 9.1. (Continued).

Element	Name of element	Included documentation	Description of documentation
15	Ignition plan	Describes the planned ignition operations	Includes fire methods, devices, techniques, sequences, patterns, and ignition staffing for single or multiple unit operations.
16	Holding plan	Describes general procedures to be used for operations to maintain the fire within the project area and meet objectives until the fire is declared out	Identifies critical holding points with map and minimum capabilities needed for all phases of implementation.
17	Contingency plant	If the objectives are not being met the contingency plan is implemented	Determines the initial actions and additional resources needed if Rx fire is not meeting, exceeds, or threatens to exceed project boundary, objectives, prescription parameters, smoke management, insufficient personnel, or other prescribed fire plan elements.
18	Wildfire conversion	The authority who will declare wildfire and parameters in which the Rx becomes a wildfire	Description will include who or whom declares a wildfire, Incident commander assignment, and who to notify. (Once declared a wildfire cannot return to a prescribed fire designation.)
19	Smoke management and air quality	Includes how project complies with air quality regulations at multiple levels (community, county, state, tribal, and federal)	Identify smoke sensitive areas that the prescribed fire may affect and describe mitigation or management techniques for reducing or redistribution emissions.
20	Monitoring	Describe the collection and analysis for monitoring	Includes detailed measurements that are used to evaluate the effectiveness of prescribed fire and at a minimum describe the weather, fire behavior, fuels and smoke dispersal during the prescribed fire.
21	Post-burn activities	Includes all activities after the burn is accomplished	This may include post-burn report, safety mitigation measures, rehabilitation needs.

Manager comment: In terms of burn plan development, the overriding goal for the burn plan is to provide a wide range of conditions designed to achieve two things: (1) desired fire effects on the vegetation, and (2) reduction in the size and/or severity of a future wildfire. Prescription parameters should be done in such a way that does not limit the decision space, making it too difficult to achieve the "perfect window." Also, it is important not to fall into the trap of thinking and using model outputs as actual truth. A range of numbers should be used to help develop environmental parameters to achieve post-fire outcomes.

Objectives, Complexity, and Prescription

The development of clear and concise objectives that are measureable and quantifiable is an important element in any burn plan. Objectives are used to design the burn prescription to produce a post-burn outcome that meets the overall land management goals. For example, for a management strategy focused on natural regeneration, one of the major objectives of a prescribed burn will likely relate to the amount and degree of exposure of mineral soil. Accomplishing this objective requires knowledge of the relationship between lower duff moisture and consumption. In burns designed to kill advanced regeneration, knowing the flame lengths required to injure and subsequently kill small trees without killing large overstory trees will be key. Therefore, a particular flame length, ignition pattern, and fire weather will be required to achieve this objective. The fire practitioner uses his/her knowledge of fire behavior, fuel amounts, fuel moisture, wind, and relative air humidity to develop the burn plan parameters.

On complex prescribed fires, clear objectives guide the burn. The fire practitioner is often aware when burning conditions may be too risky because of spotting potential, low relative air humidity, potential holding problems and other risk thresholds. Without clear and concise objectives, this type of evaluation cannot be achieved.

It is also important to note that on more complex burns the costs can increase; therefore, funding is strongly dictated by the ability to successfully fulfill the objectives.

Manager comment: We have prescribed fires I call "1 in 5" year burns, meaning that the window for implementation comes along once every 5 years. Trying to budget for those in any given fiscal year is difficult.

The prescription details the quantitative parameters such as range of the air relative humidity, temperature, fuel moistures, and wind direction and speed that work in combination to produce acceptable fire behavior. These same factors are also important for smoke management. Experience and professional judgment are used to identify or calibrate prescriptions. Simulation modeling is a tool that is often used, but professional judgment, empirical evidence, or verified actual fire behavior can override model estimates. As the complexity of the site increases, so do the prescriptions. If there are multiple fuel models or different types of ignitions, this may require multiple prescriptions and complexity analysis to identify multiple levels of management, organization, and pre-burn considerations.

Holding and contingency plans are developed for fire occurring outside of the project boundary to account for potential escape (Prescribed Fire Guide 2008). Model predictions and expert knowledge can be used to analyze previous fires that have burned during the most severe prescription limits, such as the hottest, driest, and windiest conditions. The prescription may include a short discussion on expected fire behavior and how the fire will achieve objectives. All evidence, either from modeling, monitoring data, or expert knowledge, for the prescription and contingency plans can be included in an appendix. Important elements are the time of day, duration of ignition, and season of the burn. The plan also may identify the dates or conditions when limited resources are available, and when burning will not occur.

Pre-Burn Considerations and Weather

The pre-burn considerations of the burn plan provides the list of on-site actions, considerations, and safeguards that are required prior to implementation. This may include line building, snag removal, preparation of critical holding points, and special features that need protection. This section also details the fuel sampling and weather measurements (time, source, and frequency) to be taken prior, during, and after the burn and who (person or position) will conduct the measurements. In addition, off-site actions and considerations also are discussed at this point, along with issues such as approving and distributing burn plans to dispatch and other cooperators.

Organization, Equipment, and Communications

The complexity of the prescribed fire will dictate the organization and equipment required to safely achieve the objectives and control the prescribed fire. At a minimum, a prescribed fire burn boss will be assigned to every prescribed fire. However, some locations, particularly within the WUI or on large landscape burns, may require a minimum organization level equivalent to a type III fire management team in place for all prescribed fires. Accordingly, if an escape occurs, the proper organization is present on site. An organizational chart displays individuals and associated tasks, including changes in the organization. Communication among all individuals involved is critical for maintaining safety and tactical resource needs.

Manager comment: The purpose of a contingency plan is to identify the organization needed if an escape were to occur and to plan for those contingency resources to arrive on site in a timely manner. In a perfect world, contingency resources would be on site but this is not always the case, nor is it required by policy.

Complexity Analysis

In the past century, prescribed fire was predominantly used for removing residual fuels after harvest or for preparing a site for regeneration. Today, sites that are selected for burn treatments are more complex and may contain ladder fuels, fire resistant and non-fire resistant plant species, variable topography, large spatial areas requiring multiple burning days, and increased concerns about smoke dispersion. A major component of any burn plan is to conduct a complexity analysis (fig. 9.1). The 14 elements of the complexity analysis discussed in the Prescribed Fire Complexity Rating System Guide (2004) include:

- Potential for escape (managers say smaller sites have greater propensity for escape than large landscapes)
- Number of different prescribed fire actions and dependence among them; the individual activities are dependent (similar to the links in a chain), and the success of one factor is directly connected to the success of another. The more dependence among the different actions, the more complex the prescribed fire.
- On-site value
- Off-site values
- Fire behavior
- Management organization
- Public and political interest
- Treatment objectives
- Constraints
- Safety
- Ignition procedures and methods
- Interagency coordination
- Logistics
- Smoke management

For each of these elements, a rating of low, moderate or high are given for each of three risk factors (fig. 9.1): (1) *risk*, or the probability or likelihood that an adverse event or situation may occur, (2) *potential consequences* if an adverse event or situation occurs, and (3) *technical difficulty,* which indicates the skills needed to implement the project and address unexpected events. For detailed descriptions of how these factors are used rate the elements please refer to Prescribed Fire Complexity Rating System Guide (2004).

Common Oversights in Prescribed Fire Planning

Within the planning and preparation phase, areas consistently cited by managers as problematic were the lack of smoke management, simplifying potential challenges in burning heavy fuel loads or in timing of the burn, weakness in contingency planning for unexpected events, and not thoroughly identifying management action points. The lack of smoke management can negatively influence public perception; thus, it is important to appropriately model and consider smoke impacts to avoid negative impacts to public health and safety. In addition, during the planning stages, the influence of heavy fuel loads on fire behavior is often simplified, resulting in unexpected outcomes after ignition. Timing of burns is also critical and there are potential risks if the burns are conducted prior to the normal fire season.

Manager comment: A related issue is unfamiliarity with local fuel types. Many practitioners do not realize, for example, that old western redcedar needles (gray, but still attached to branches) often burn as readily as the red needles of other species. They may not recognize a particular species of shrub as flammable or recognize that drought-stress has made some shrub species more flammable than typical. The failure to recognize what drought stress had done to shrub flammability can compromise prescribed fire outcomes.

Descriptors	
Objectives	Public and political interest
Potential for escape	Constraints
Links among activities	Safety
Off-site values	Ignition procedures
On-site values	Interagency coordination
Fire behavior	Logistics
Management organization	Smoke management

↓

Factors
Risk
Potential consequences
Technical difficulty

↓

Complexity Determination

Figure 9.1. A complexity analysis has 14 elements, with each rated on three factors. The combination of this analysis results in a complexity determination.

Basal rot can also play a role in igniting otherwise live trees. In some cases, these rot pockets may be hidden by the duff layer. One fire manager described a burn in Arizona in which several large ponderosa pines were lost due to fire getting into the tree through hidden basal rot pockets.

Lastly, our ability to keep snags and downed wood from burning is much more limited than many recognize. Someone may spend a lot of time and energy during the day to protect snags and downed wood, only to lose them overnight. It is not very encouraging to come back to a pile of white ash in the place of a big log in which you had spent so much time and energy protecting the day before.

In all of these cases, adequate modeling, monitoring, attention to fuel moisture trends, and use of other sources of information are beneficial to fully understand the potential for spotting outside the unit, as well as for evaluating the best time to ignite given the potential for extended burning or smoldering. No matter the complexity of the prescribed fire, the ability to manage the unexpected depends on having comprehensive contingency plans. If contingency plans encompass a full range of potential problems, a prepared team can recognize subtle changes and take the appropriate action quickly. Developing a thorough contingency plan can also help in identifying the required qualifications when assembling the burn team. Contingency plans identify management actions trigger points or thresholds (for example, weather, fire behavior) and these locations are discussed and briefed prior to implementation. In addition, the briefing details the availability and deployment period of contingency resources. On the day of the burn, contingency resource availability often is validated and coordinated prior to ignition and during each phase of the burn until it is declared out.

Manager comment: Escaped burns often occur days if not weeks after ignition because of a lack of long-term commitment to monitoring/patrolling the burn and assigning contingency resources.

Implementation of Prescribed Fire

There are many intuitive ways to influence fire behavior and fire severity. The more experience a fire practitioner has, the more they are able to use a variety of techniques. Some of these include: fuel manipulation, firing techniques, live and dead fuel moistures, and timing between ignitions. In addition, the number of people involved in ignition, and the fire weather (relative humidity, air temperature, wind speed, etc.) during ignition all influence fire intensity. Conditions also vary throughout the day and across the site (slope aspect or relief) and subsequently affect fire behavior; therefore, continuous vigilance and organization are needed to avoid unplanned consequences.

Weather and fuel considerations and their effect on fire behavior are critical components in planning and executing a prescribed fire. Large scale (synoptic) weather patterns can be used to estimate favorable burning weather conditions or when burning weather conditions will deteriorate. Important weather elements are wind speed, relative humidity, air temperature, rainfall, and air mass stability. These elements influence fuel moisture, and short- and long-term fire behavior, which all determine the success of a burn. Steady and persistent wind speed and direction and homogeneous slopes provide the most consistent prescribed fire behavior. Some wind is usually desired to give the fire direction and prevent heat from rising directly into tree crowns. However, high wind speeds can cause fires to spread too quickly and increase spotting distances and become too intense. Air relative humidity reflects the moisture in the air—if too low, prescribed burning can be hazardous and it may become difficult to hold the fire. If air relative humidity is too high, the fire may not burn to the intensity required to meet objectives. Temperature affects moisture changes of the live and dead fuels. High temperatures dry fuels quickly. If the fuels are in the sun, they can become much warmer than the surrounding air even when the relative humidity of the air is high. Low temperatures can retard fire intensity. Also, increases in moisture, either in the air or in the fuel, can reduce fire behavior and movement.

Escaped Prescribed Fire and Near Misses

There is always the potential for a prescribed fire to escape and result in a negative outcome. Every year, up to 5,000 prescribed fires are implemented and approximately 99 percent of those fires are successful in that there was not an escape or adverse effects (near misses). However, approximately 1 percent of these fires (up to 50 fires per year) result in damage or undesired outcomes (Dether 2005). A near miss is when a potential accident did not occur, either through prevention, education, hazard reduction, or luck (NWCG Glossary of Wildland Fire Terminology 2011) http://www.nwcg.gov/pms/pubs/glossary/n.htm. Close calls and near misses are regarded as a type of failure that reveals potential and ongoing danger, rather than as evidence of the organization's success and ability to avoid danger (Keller 2004).

There are two interconnected factors that, if not properly managed, can lead to an increased probability of a potential escape or near miss: lack of mindful communication and the snowball effect. Mindful communication is essential for successful prescribed fires because it enforces continuous, open, and comprehensive communication between agency administrators, planners, cooperators, dispatch centers, and implementation personnel. When gaps or weaknesses in coordination and communication occur, there is an increased probability of an unsuccessful burn. The snowball effect refers to the observation that unexpected weather events or small problems are encountered throughout the prescribed fire which have a cumulative effect that can significantly reduce the probability of a successful burn. Often, the accumulation of multiple small problems can be mitigated through comprehensive mindful communication.

During prescribed fire implementation, onsite leadership is critical. Fire behavior, weather predictions, and staffing levels fluctuate on long-term burns; therefore, as the complexity of the burn increases the onsite leadership must also increase accordingly. Often, typical problems on short-duration burns (one operational period) are not apparent until after ignition; therefore, it is important that risks, benefits, resource needs, and comprehensive contingency plans are identified before any burn.

Atmospheric Stability and Atmospheric Dispersion

Mixing height and the Haines Index are two descriptors that aid in determining atmospheric stability. The mixing height is the height at which the lower atmosphere will undergo mechanical or turbulent mixing, producing a nearly homogeneous air mass. This determines the altitude at which smoke will be dispersed from a site. The Haines Index is a measurement that helps determine the potential for fire growth. This index is based on a combination of atmospheric stability and dryness of the air. The atmospheric stability is calculated by calculating the difference in temperature of two atmospheric layers. The dryness of the air is calculated based on differences in temperature and moisture content. The Haines Index ranges between 2 and 6, with a value of 2 indicating a moist, stable, lower atmosphere with very low potential for fire growth. A value of 6 indicates a dry, unstable, lower atmosphere and high potential for fire growth.

During a prescribed burn, the stability of the atmosphere impacts air quality, visibility, and fire behavior. Air rises when it is warmer than the surrounding air. The rate and height that heat rises into the atmosphere is determined by the stability of the atmosphere. If the atmosphere is unstable, heat can rise rapidly due to the large differences in air temperature (air temperature typically decreases with altitude). High instability allows more convection, which can increase fire intensity. An unstable atmosphere also carries smoke into the upper atmosphere, helping to disperse it. Sometimes, the atmosphere is stable and resists the upper movement of heated air. This often occurs when air temperature decreases slowly with increasing altitude, creating an inversion.

High Reliability Organizing

Nasiatka and others (2008) identified consistent elements that tend to be found in evaluations of escaped fires. They summarized these elements and placed them within the context of the High Reliability Organizing (HRO) concept of mindfulness. A HRO is an organization that operates in a high-risk environment but maintains a relatively low accident and error rate. Mindfulness is managing for the unexpected and paying close attention to small, at first appearance, inconsequential problems and being wary of oversimplification and sensitive to operations and possible glitches so they can be corrected or addressed quickly (Welck and Sutcliffe 2007).

Anticipating needs becomes particularly important for long-duration burns (multiple ignition periods). With this added element, future conditions and resources may need to be anticipated as far in advance as possible to account for potential changes in conditions over multiple operational periods. Simultaneously conducting multiple burns can have both advantages and disadvantages. The primary disadvantage is that unexpected problems can increase exponentially as problems with communication, response time, the splitting of available resources, and coordination of efforts and resources among the burns becomes problematic.

The most interesting factors that may lead to an escaped prescribed fire or a near miss are the pressures and expectations of the burn boss and team. Often these are self-imposed pressures—for example, a feeling that one has to treat acres. Consequently, productivity can be an added pressure. In addition, there are professional and personal rewards in increased productivity and the desire for these incentives can lead to further self-imposed pressure.

Manager comment: In some cases, there are substantial pressures to complete burns in a manner that reduces the cost per acre.

Burning when the atmosphere is stable keeps the smoke closer to the ground, reducing visibility, and limiting its dispersal. This often occurs at night when air temperatures cool near the ground creating a stable air layer. Indicators of an unstable atmosphere include observations of dust devils, gusty winds, and clouds that show vertical growth. Indicators of a stable atmosphere include steady winds, clouds that form in layers, and poor visibility due to haze and smoke.

Incorporating all of these factors to ensure a successful burn varies depending on variety of factors such as location, topography, and previous weather patterns, to name a few; therefore, the fire practitioner has to use their knowledge and skills in order to determine the appropriate time to begin, hold, or stop burning—all of which depend on the intuitive knowledge of the burn boss and the objectives of the prescribed fire, weighted within the risk of potential escape or other complications.

Firing Techniques

There are various firing patterns that can be used to ignited prescribed fires (Wade and others 1989; Wade and Lundsford 1990; Weir 2009). The selected technique is dependent on the fuels, topography, and weather needed to meet goals but not damage forest resources. Regardless of the technique or combination of techniques that are used, firing begins at an established anchor-point and proceeds carefully with attuned situational awareness concerning changes in wind direction and speed, as well as topographic features (ravines, V-shaped canyons, hollows, steep slopes, rolling material, spotting), which may result in unexpected fire behavior. Each firing technique has its unique attributes, advantages, and disadvantages. In this section, we introduce each technique and provide short definitions. These are general descriptions and the exact implementation will vary for different situations. Please refer to Weir (2009) and Wade and others (1989; full reference in the Further Reading section) to obtain more detailed descriptions of the different firing techniques. Learning from experienced individuals is a necessary element when learning to use prescribed fire, and one of the best ways to learn the advantages and limitations of different firing techniques is to work with experienced practitioners.

The most common firing techniques are backing, strip, spot firing or point source (sometimes referred to as dot firing), flanking, and chevron. Head fires are not commonly used since they tend to have a fast spread rate, wide flaming zone, and long flames. Once it is lit, there is little to no control.

Backing fires are started along a baseline (road, plough line, stream or other fire barrier) and allowed to back into the wind or downhill. Backing fires are effective in many fuel situations and tend to result in less heat transferred to the overstory canopy. However, backing fires take time, and there is a chance that more heat is produced in the lower duff, which can damage roots if duff moisture is insufficient. Backing fires work best with continuous fuels and are effective in heavy fuels—they consume fuels better than other ignition patterns, but results depend on the size of woody fuels due to variability in fuel moistures.

Manager comment: Backing fires also have an increased potential for developing fingers (based on heterogeneity of fuels and slope), which in turn could create opportunities for these fingers to turn into head fires and make short runs that burn out the areas between fingers.

Strip-head firing involves a series of lines of fire set progressively upwind of a firebreak. In this method, no individual line of fire can develop a high energy level before it reaches either a firebreak or another line of fire. The number of lines and strip width is based on desired flame length. This tends to be the most commonly used technique

The Value of Patience

Some prescribed fires are becoming more complex—involving understory burning or the reintroduction of fire in old-growth stands or other locales where the prescribed fire outcome is of critical importance (from Kilgore and Curtis 1987). In these situations, and in most prescribed burning contexts, patience can be an important element. Patience comes into play in many facets of the burn, such as waiting until the prescription parameters are met; or in strip firing, it may require letting one strip die down before starting another (and not allowing strips to get too wide, which can happen when ignition crews get in a hurry to finish). Thus, patience may mean not moving too fast to take an action but also not moving too slowly as well. Patience means demonstrating "torch finesse"—occasionally raising the drip torch, watching the last strip, and observing fire behavior. The flame length can be a good indicator of fire intensity and it varies greatly based on strip width and rate of ignition. If the flame length is too great, then narrow the strips; if it is too little, then widen the strips slightly. Small ignition crews of two to eight persons may be better than large crews. Adding more crew members can speed up burning but can sacrifice overall crew patience. Good communication is essential between holding, ignition, and burn bosses.

and is faster than a backing fire. Strip fires can consume large areas in a shorter period of time than backing fires.

Manager comment: Fundamentally, strip fires are actually "strip head fires"… that are true head fires that are kept under control by maintaining short strip widths in which the fire can grow.

Spot firing involves a grid of spot ignitions that can produce a fire with intensity greater than a backing fire, but less than a heading fire. It is often used in conjunction with strip firing. It conserves the amount of fuel used for ignition; however, it can potentially lead to fires that develop hot spots if the spots are incorrectly spaced. Therefore, timing and spacing of individual ignition spots are critical to successful application of this method. Point source or spot firing is good for removing pockets of heavy fuels when fuel moistures are high.

Center ring firing is useful in cut-over areas where a hot fire is needed to reduce fuels. The firing technique encircles the perimeter of an area. However, it can trap wildlife because they have no escape route. This technique is useful in burning isolated areas that have good escape routes and safety zones. It works best when winds are light and variable. The firing method can be used in any season, given the right conditions. This type of fire tends to develop a strong convection column and can cause spotting.

Chevron firing is best suited for unique terrain features. This technique is used to burn down slopes on ridge points. This technique uses a series of igniters starting at the same point at the top of ridge. A line of fire is set in a V-shaped pattern to burn ridges, points, or ends and the burn progression must be downhill.

Manager comment: Chevron firing can also pull heat and smoke off the line. When used correctly the tip of the V starts to pull together.

Monitoring

For prescribed fire, monitoring includes the collection and analysis of repeated observations or measurements to evaluate changes in conditions and progress toward meeting the management objectives. Monitoring includes identifying the elements that can directly address quantitative objectives needed for an evaluation of prescribed fire success. During the burn, measurements in relation to the weather, fire behavior, and live and dead fuel moistures and smoke dispersal are often recorded with individual assignments to each set of tasks (see Chapter 10 for further discussion on monitoring).

Unique Attributes That Favor Specific Post-Fire Outcomes

A successful burn is one that meets objectives without substantial unexpected events. Fuel managers explicitly expressed that expert knowledge is invaluable in determining when to ignite a prescribed fire. However, there are a variety of general prescription parameters that can lead to preferred post-fire outcomes in meeting the objectives of the burn. Prescribed fires tend to be predominantly surface fires, ignited with the primary objective of removing fine woody fuels. They can also be used for other resource management objectives such as exposing a portion of the soil for planting and natural regeneration of trees, or promoting sprouting for browse. Therefore, the type, amount, and moisture of the surface organic materials can greatly influence a post-fire outcome. Prescribed fire can also be used in restoration projects in old growth stands or as a thinning agent to reduce seedling density. To successfully determine if a prescribed fire can achieve these outcomes, there are some parameters that may be useful in the planning and implementation of the prescribed fire. Accordingly, we provide some suggestions below.

Live and Dead Fuel Moistures

Lower duff

Prolonged consumption of accumulated duff around the base of old trees (duff mounds) is a primary contributor to mortality in North American pine species (for example, Hood 2010). Duff is defined as decomposing organic matter above the mineral soil and below freshly fallen litter (Miyanishi 2001; Miyanishi and Johnson 2002). Duff is generally composed of two distinct layers: an upper fermentation layer of organic material, including branchwood, cones, and bark in the early stages of decomposition and a lower humus layer of mostly indistinguishable organic matter (Harrington 1987). The humus layer, or lower duff, is in an advanced state of decomposition and is dark brown to black in color (Potts and others 1986).

Lower duff is primarily consumed by smoldering combustion (Frandsen 1987; Miyanishi and Johnson 2002). Several characteristics of duff—moisture content, mineral content, depth, and bulk density—have been identified as the primary determinants of rate and amount of duff consumption and resulting damage in pine species (Hood 2010). Among these, moisture content is most important, with the probability of sustained smoldering combustion inversely related to duff moisture content (Hungerford and others 1991; Valette and others 1994). Adequate soil and duff moisture can protect tree roots and micro-organisms and minimize volatilization of nutrients (Hungerford and others 1991). Studies have shown that lower duff burns independently of surface fuels below 90 percent moisture content (Brown and others 1985; Norum 1977; Sandberg 1980). Conversely, duff rarely burns above a moisture content of 120 percent. In controlled laboratory burning of lower duff from a ponderosa pine dry mixed conifer stand in the southern Klamath Mountains, smoldering combustion was halted at moisture contents exceeding 102 percent moisture content, and was variable below that threshold (Garlough and Keyes 2011; fig. 9.2).

Mineral content is secondarily important through its interaction with moisture content; higher levels of mineral content in the duff require drier duff in order for consumption to occur (Garlough and Keyes 2011; fig. 9.3).

Live fuel moistures

Manager comment: I use live fuels moistures (on site and from the national database) to target species I want to remove as well as ones I want to keep. I also use them to track fuels I have identified that I want to use as a natural fuel break, mostly sage but other brush too.

Moisture content of shrubs and herbaceous vegetation will influence whether this vegetation is either a heat source or heat sink in contributing to surface fire behavior (Agee and others 2002). The importance of live fuel moisture in influencing fire behavior is not new and has been used extensively in estimating fire danger (in fact, it is an important aspect of the Fire Danger Rating system) (Weise and others 1998b). In the dry mixed conifer forests, where shrubs and herbaceous vegetation are abundant, trends in diurnal and seasonal trends in live fuel moisture can dictate whether a prescribed fire is successful. Interestingly enough, we found limited information concerning the use of live fuel moistures in burn prescriptions. Moreover, Jolly (2007) indicates that despite decades of research in fuel moisture dynamics, there is a lack of information on the contribution of live fuel moisture to fire behavior. However, as stated above, live fuel moistures can be an invaluable tool when applying prescribed fire either in identifying fuel breaks or to focus treatments on particular species for maintenance or removal.

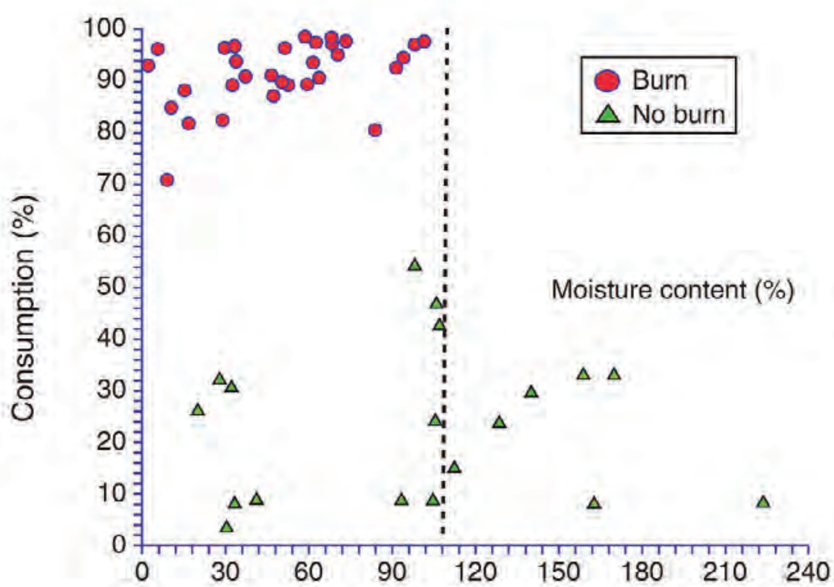


Figure 9.2. Data from a laboratory combustion study of ponderosa pine duff from California's southern Klamath Mountains (Garlough and Keyes 2011) illustrates the association of lower duff moisture content to percent consumption. The dashed line denotes the upper boundary of moisture contents (102 percent) beyond which duff failed to sustain smoldering combustion. Below the threshold, percent consumption proved highly variable.

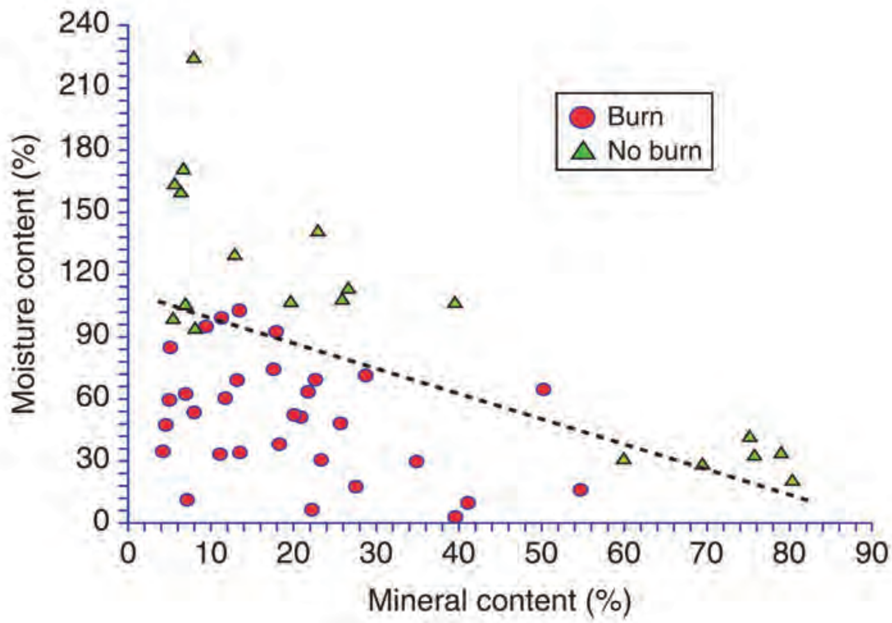


Figure 9.3. Data from a laboratory combustion study of ponderosa pine duff from California's southern Klamath Mountains (Garlough and Keyes 2011) illustrates how lower duff's moisture content and its mineral content (percent inorganics) interact to determine its ability to ignite and burn. The dashed line roughly demarcates Burn and No-burn outcomes (circles and triangles, respectively). Moisture content is the most important factor; as moisture content drops, the probability of smoldering combustion declines accordingly. But the duff's mineral content suppresses its ability to combust at any moisture content. In this example, duff combustion was a common outcome at higher moisture contents (y-axis), when mineral contents (x-axis) were low. But combustion outcomes declined at higher mineral contents, and combustion failed at mineral contents above 60 percent, even when that duff was very dry.

Seasonality of Burning

The majority of lightning fires historically burned during or at the end of the growing season; however, prescribed fire is often implemented during the spring or fall. This difference in timing of burns is due to the operational and liability constraints associated with the heavier fuel loads present in these fire-excluded forests, safety concerns, smoke management, and biological management (Knapp and others 2009). From an ecological point of view, there is concern that burning outside of the historic range of variation will result in a disruption of ecological processes and, in some cases, have negative impacts on plant and wildlife species. In this section, we briefly discuss the expected fire behavior and effects that may occur for prescribed burns implemented outside of the historical fire season.

Manager comment: Most deliberate human-caused ignitions prior to 1850 were in late winter/early spring and in fall, before and after the primary growing seasons. Accidental human caused fires could occur at any time of the year (escaped campfires). Deliberate human ignitions during the growing season were most often acts of war, intended to drive enemies or deprive them of cover or food. We need to stop pretending or denying that human-caused fires did not occur over the last 15,000+ years.

Historically, the majority of fires in dry mixed conifer forests within our synthesis area occurred in late August to October (in other words, late in the growing season) (Knapp and others 2009). This historic fire season corresponded to a time when air temperatures were high, live and dead fuel moistures were low, and soils were dry. Burning under these conditions would have allowed a substantial amount of fuel to be consumed and produced heat that impacted stand structure and species composition. Fires during this period would also have favored fire-adapted vegetation, such as the thick bark which protected ponderosa pine and western larch. However, there are times of the year when even resistant species are susceptible.

Today, we burn when there is less risk of escape such as in the spring or late fall. However, the intensity generated during the prescribed burns may be similar to or exceed historic fires due to the heavy amounts of fuels that have accumulated through the many years of fire exclusion. In dry mixed conifer forests, this similarity in fuel consumption and fire intensity between the historic fire season and the current prescribed burn season is thought to override the importance of organism phenology (Knapp and others 2009). This is especially relevant when comparing the differences of not burning to burning in different seasons. However, this is not to state that phenology does not matter. In fact, understanding changes in plant susceptibility throughout the different seasons can help in developing plans that meet specific objectives, especially for reentry burns when fuel loads are lower.

Manager comment: These are the same conditions under which much burning by Native Americans occurred and for much the same reason—maintaining control of the fire. We differ from Native Americans in that our early season burning is rarely before the period of most active growth. Instead, it is during the period of most active growth.

Fuel consumption

In general, moisture conditions differ for spring and fall prescribed burns. Typically, spring fuel (prior to green-up) and soil moistures are higher, due to spring precipitation patterns and snowmelt. In contrast, fall fuel and soil moistures are low, as a result of summer drying. In terms of fire intensity and fuel consumption, spring burns often result in less fuel consumption, are less intense, and result in patchier surface fuel consumption. Examples of individual studies include Kauffman and Martin (1989); Knapp and others (2005; Sierra Nevada); Monsanto and Agee (2008; Cascade); Reinhardt and others (1994; northern Idaho); and Hungerford and others (1991; northern Rocky Mountains). However, consumption and intensity are more a function of moisture conditions rather than season. Therefore, if an area has experienced a dry winter and spring, a spring prescribed fire could result in similar fire intensity and fuel consumption as one that takes place in the fall (Swezy and Agee 1991). For that reason, when evaluating and reporting prescribed burning results, it is important to provide information on weather conditions, drought status, fuel moistures at the time of the burn, fire behavior (in other words, fire intensity, fire type), and time of year (Knapp and others 2009).

The influence of the burning season and plant phenological state on mortality is mixed. Biologically, the actively growing tissue may be more susceptible to fire damage than dormant tissue. Burning early in the growing season reduces the ability of a plant to photosynthesize and store carbohydrates. Instead, the plant must use stored carbohydrates to regrow the photosynthetic tissue and heal other fire injuries. However, the majority of research on season of burn and plant mortality suggests that fire intensity from fuel consumption, which is a function of fuel moisture and fuel availability, can override phenology. It is the damage induced by the fire that explains mortality, rather than the seasonal susceptibility of trees (Harrington 1993; McHugh and Kolb 2003;

Perrakis and Agee 2006; Schwilk and others 2006; Thies and others 2005; Thies and others 2008) and herbaceous plants (Kerns and others 2006; Knapp and others 2007; Knapp and others 2009), at least in initial burn entries.

Soils

The impact of burn season on soils is related to soil moisture, fuel consumption, the heat produced, and burn duration. Each of these factors is influenced by moisture availability, which is typically higher in the spring than the summer or fall. Fuel consumption and duration of heat is influenced by fuel moisture. The higher the fuel moisture, the more energy it takes to evaporate the water, bring the wood particles to ignition temperature, and burn. Higher fuel moistures reduce the potential fire intensity that would heat the soil. Soil moisture also creates a buffer to soil heating. As with wood, moist soils take substantial energy to heat up. Therefore, the depth that heat penetrates the soil is largely dependent on soil moisture (Campbell and others 1995); dry soils heat up quicker and the heat goes deeper (Busse and others 2005; Frandsen and Ryan 1986; Monsanto and Agee 2008). Heat penetration impacts roots (Smith and others 2004), soil nitrogen (Hamman and others 2008; Hatten and others 2008), and soil microbial activity (Hamman and others 2008). Based on these factors, managers can tailor their burning based on fuel moisture and soil moisture conditions in order to meet their objectives. For instance, if fuel consumption with limited damage to soils or roots is the objective, then burning when fuel moisture is low, but soil moisture is high (for example, above 100 percent moisture content) could be a trigger for a burn window (figs. 9.2 and 9.3.

Wildlife

Wildlife that occupies fire-adapted forests presumably have behavioral adaptations that promote their ability to escape from fires. However, wildlife may have coevolved with a fire season that peaked after their young had been reared and were able to escape fire. There is concern that our current practice of burning during the spring months might negatively impact wildlife populations because they are still giving birth and rearing their young. At this stage in development, many of the wildlife species are unable to escape the fire, although some species do have the ability to produce young again in the same year. However, much of the evidence for seasonality of burning and impacts to wildlife populations is anecdotal and further study is needed (Pilliod and others 2006; Knapp and others 2009). Nevertheless, many of the managers we interviewed stated that burning during the spring is often limited to protect wildlife populations rearing their young.

While direct mortality of wildlife from a prescribed fire is a concern, the change in the habitat due to a fire is likely the larger impact to wildlife (Pilliod and others 2006). For example, many wildlife species use snags and coarse woody debris for forage and habitat. The loss of these important habitat features could negatively impact some wildlife. In some cases, protection of snags during burning and ensuring that some coarse woody debris (Brown and others 2003) is still present can help alleviate the loss of important habitat features. While the loss of old snags and coarse woody debris is a concern, prescribed fire often creates new snags, especially in areas that have been impacted by full fire suppression efforts. Burning can also alter the vertical and horizontal continuity of vegetation, impacting those wildlife species that prefer closed-canopied conditions, while favoring those that prefer open-canopied conditions. Prescribed burning can aid in creating heterogeneity across the landscape and allow for areas with different densities and species composition to serve as population source and sink areas to help maintain population viability. As mentioned above, fuel moisture conditions when burning impact fire intensity and the amount of fuel consumption. Therefore, burning in the fall versus the spring often results in different fire intensity and fuel consumption.

The impact of prescribed burning and the season of burn on wildlife populations is complex (Knapp and others 2009; Pilliod and others 2006). Determining impacts is hindered by natural annual variability in populations, difficulty in implementing valid study design, and variability among sites (Pilliod and others 2006). Until more studies are performed, resource specialists are limited to their knowledge and experience to aid in making informed decisions. In a synthesis of fuels reduction treatments and impacts on wildlife species, Pilliod and others (2006) suggest several factors to consider: species distribution and abundance, migratory and dispersal characteristics, habitat associations, and potential responses to habitat alterations. We refer the reader to that synthesis to find more detailed information about specific wildlife species (see chapter 6).

Evaluation of the impact of prescribed fire and other fuels reduction treatments on wildlife habitat is currently being explored. The Wildlife Habitat Response Model is a web-based model that provides information about specific species habitat associations, life history requirements, potential predators and hazards, and how a fuels reduction treatment might influence these factors. The information is based on published literature about species/habitat relationships and provides information about how different fuel treatment activities might alter the habitat. The Wildlife Habitat Response Model can be found at: http://forest.moscowfsl.wsu.edu/fuels/whrm/whrm.html.

Prescribed Fire as a Thinning Agent

Successful modification of forest structure with prescribed fire has been demonstrated across a range of forest types and stand development stages (Battaglia and others 2010; Peterson and others 2007; Youngblood 2010). The level of success of using prescribed fire is dependent upon the target tree species and size, the availability of fuel to contribute to fire intensity, the weather conditions, and the live/dead fuel moisture in which the burn is implemented. As discussed in Chapter 3, tree species have various levels of fire resistance. A manager can tailor a burn prescription to exploit or protect these weaknesses in order to meet objectives. This is especially helpful in mixed species stands where the survival of one species is desired over another. In this section, we briefly discuss types of fire injury, thresholds for post-fire injury and related mortality, and possible techniques to create the conditions to induce injury.

Fire induced mortality in trees requires damage to the crown, the cambium, the roots, or a combination of all three. Crown injury through scorch and/or consumption of the foliage and buds reduces the photosynthetic capacity of a tree, which reduces the amount of sugars produced to keep the tree alive. Cambial damage occurs by heating the cambial tissue to temperatures that kill the tissue, girdling the tree and reducing the transport of nutrients from the needles to the roots. This kills the roots and reduces the water intake of the tree. Root tissue can also be killed via soil heating, resulting in a reduction in nutrient intake. The rate of death is often variable, depending on the damage to each of these factors. Often, fire induced tree mortality can take up to three years if the damage is moderate.

Crown injury is often classified as crown scorch and crown consumption. Crown scorch occurs when foliage tissue is heated to a lethal temperature, but the foliage does not ignite. When the heat generated from the fire is hot enough to ignite the foliage, crown consumption occurs, which removes the foliage and often kills the buds. Without buds, the tree cannot produce new foliage (flush) and death is imminent. For some fire-adapted tree species, such as ponderosa pine, thick, large buds and long needles protect the buds, and the buds often remain alive even if crown scorch occurs. However, mortality is still possible, depending on the amount of crown scorch and other damage to the cambium and roots. The probability of crown injury is a function of proximity of the crown to the ground, the intensity and duration of a fire beneath the crown, and the susceptibility of a specific tree's foliage and buds to heat.

Cambial injury occurs when cambial tissue is heated to a lethal temperature. Tree diameter and bark thickness influence the amount of heat that reaches the cambium. In general, tree diameter and bark thickness are positively related, but this relationship is very species-dependent. For example, even though a mature Douglas-fir, grand fir, and white fir may have the same diameter, the bark thickness of the white fir and grand fir is substantially thinner and more susceptible to cambial damage. Tree bark acts as an insulator to the cambium; therefore, bark thickness and thermal resistance combined with fire intensity and duration determine the extent of cambium damage (Ryan and Frandsen 1991; van Mantgem and Schwartz 2003).

Mortality thresholds

The ability to predict post-fire mortality based on damage to crowns, cambium, and roots is essential for planning prescribed burns. Over the past several decades, numerous studies have identified thresholds based on easily measured crown and cambial damage variables to develop post-fire mortality predictions using logistic regressions for a number of coniferous species (Hood and others 2007a; Sieg and others 2006; Woolley and others 2012). In a recent review, Woolley and others (2012) summarize the various tree mortality logistic regressions and the explanatory variables (damage) used and discuss how the models were developed, validated, and interpreted. They report on over 33 studies that have developed post-fire mortality prediction equations for 19 coniferous tree species and three hardwood species. These include white fir, grand fir, subalpine fir, red fir, incense-cedar, western larch, tanoak, whitebark pine, lodgepole pine, coulter pine, Engelmann spruce, Jeffery pine, sugar pine, ponderosa pine, California foothill pine, Douglas-fir, Oregon white oak, canyon live oak, coast redwood, giant sequoia, western redcedar, and western hemlock. Hood and others (2007a) developed a guide to interpret tree mortality using logistic regression outputs to use for post-fire management and prescribed burn plans. In addition, they developed a supplemental field guide that includes photographs of the ranges of fire-related injuries and descriptions on how to measure each in the field (Hood and others 2007a).

The logistic regression models are intended for planning purposes to facilitate management activities. Although there are over 100 logistic regressions published in the literature, only one model (Ryan and Amman 1994) is being used in the simulation models used by federal agencies (Woolley and others 2012). These models require diameter at breast height (a surrogate measure for bark thickness) and crown scorch as input variables. For prescribed burning purposes, Hood and others (2007b) reported that these models correctly predicted overall stand-level mortality within $\pm$ 20 percent of the observed mortality for lodgepole pine, whitebark pine, Jeffery pine, Douglas-fir, and sugar pine. However, red fir, incense cedar, and western larch mortality was overpredicted and western hemlock was underpredicted. When attempting to predict individual tree mortality, the accuracy of these models decreases. Better accuracy might be obtained by including a root injury, cambial injury variable, and/or utilizing local bark thickness, which can vary by site and geographic region and is being used in the simulation models used by federal agencies (Ryan and Amman 1994; Woolley and others 2012). Alternatively, using locally derived equations in conjunction with the simulation model predictions could aid in predicting tree mortality. Woolley and others (2012) provide a list of geographically derived logistic regressions that predict mortality based on tree characteristics and damage variables.

The differences in mortality thresholds for different tree species and tree sizes highlight their susceptibility to different damage pathways and give managers several options when designing burn prescriptions. For example, some tree species are highly susceptible to crown damage due to low crown base heights, highly flammable foliage, and/or heat sensitive buds. In these cases, mortality can be achieved with fast-moving, low-intensity surface fires that cause crown scorch and consumption, but with light damage to the cambium and roots. Burning when ambient air temperature is higher can aid in additional scorch because less additional heat is needed to raise foliar temperature to lethal levels (Albini 1976). Wind can also be used to facilitate foliage scorch or consumption. At high wind speeds, flame lengths increase and can ignite foliage. Wind also influences heat dissipation, so at low wind speeds, heat moving toward the crowns can increase the amount of crown scorch, whereas with high wind speeds, the heat is dissipated decreasing crown scorch (van Wagner 1973). In circumstances where a prescription limits flame lengths, a slow-moving fire with slow windspeeds that results in moderate levels of crown scorch and moderate to high damage to the cambium can achieve mortality. If tree crowns are too high to ignite or scorch, then heat damage to the cambial and root tissue from flaming and smoldering combustion will be needed to cause mortality. This is possible if managers burn under drier conditions to allow larger-diameter (>3 inches) fuels to contribute to fire intensity.

Prescribed Burning Masticated Fuels

Recently, within the last decade, the use of masticators to treat non-commercial vegetation have been used to treat small diameter material, ladder fuels, shrubs, and regeneration (Battaglia and others 2010; Glitzenstein and others 2006; Kane and others 2009). The application of mastication is discussed in Chapter 8; thus in this discussion, we will focus on information concerning fuels and what information that is available on fire behavior in prescribed or laboratory burning. Masticated materials are different from natural or logging slash fuel beds (Battaglia and others 2010; Kane and others 2009). They differ in 1 and 10 hour fuels distribution, bulk density, and particle shape (shredded or has angular edges) (fig. 9.4). The fuel beds created are influenced by the material that is masticated (shrub species and or tree size), the distribution of the material across the site (heterogeneous or homogeneous distribution), the type of machine used, the intensity and duration of the mastication (which can influence piece size), and the contract guidelines. Mastication is different than using a chipper; with mastication there are more options for controlling piece size and distribution that can influence the fire behavior. Chips are typically small and compact versus masticated material, which are shredded or in chunks and usually vary in fuel size across the site. Therefore there is considerable variability from site to site. Moreover, current fuel models do not reflect the characteristics of masticated material, so fire behavior models may not provide satisfactory predictions (Busse and others 2010; Knapp and others 2011; Kreye and others 2011). Also the woody debris planer intersect method (Brown 1974) to measure woody fuels tends to underestimate the amount of 1 hour and 10-hour fuels compared to a plot method (50 x 50 cm frame) that collects and weighs the fuels in order to develop unique regression estimates of fuel loadings as a function of depth. In contrast, for 100- and 1000-hour fuel loads, the planer transect method estimates fuel loads more effectively than the plot method (Kane and others 2009; Kreye and others 2011).

There are a limited number of studies that have either quantified fire behavior in laboratory studies or under prescribed fire conditions. Results indicate:

1. Masticated fuelbeds burn with shorter flame lengths and slower rates of spread than natural or slash fuel beds (Knapp and others 2011) (fig. 9.4).
2. Duration of heating tends to be longer (Busse and others 2010).

a

b

c

Figure 9.4. Burning of masticated material on Boise Basin Experimental Forest, Idaho. Burning occurred in early spring with lower duff moisture greater than 100 percent. Flame lengths were less than 18 inches (a and b). Masticated material makes a unique fuel bed (c) that burns differently than logging slash. There currently is no fuel model that represents this material.

3. Soil moisture influences soil heating. Busse and others (2010) suggest that soil damage from prescribed burning will be nominal if soil moisture contents are 20 percent or greater (under laboratory conditions).
4. Scorch height on residual trees was substantially greater (Knapp and others 2011). They suggest that crown scorch can be mitigated by adjusting burning prescriptions such as burning in cool temperatures, or when wind speeds are sufficient to disperse heat horizontally. Altering firing techniques may also aid in mitigating the amount of upward heat that is produced. In summary the burning of both chipped and masticated material is highly variable, so caution is suggested in burning this material until more research and experience is gained as to the methods, parameters, and resulting outcomes.

Minimizing Mortality of Large Ponderosa Pine

Many of the dry mixed conifer forests have not burned in over 100 years. As a consequence, high litter and duff accumulations have increased in the areas surrounding large old ponderosa pine and western larch (Hood 2010). In restoration efforts of old growth forests, large-diameter tree mortality has been documented from basal injury caused by long-term smoldering of duff mounds. One study found that soil temperatures in smoldering duff mounds exceeded 799 °F (400 °C) with temperatures above 212 °F (100 °C) for over 16 hours (Hartford and Frandsen 1992). The first introduction of fire into a long unburned forest has two potential factors that may lead to delayed large-diameter tree mortality (three to five years after the prescribed fire). Smoldering duff mounds can girdle the cambium. In addition, if there is sufficient damage to fine roots, which have migrated into the duff layer, the damage can lead to a weakening of the tree and opportunities for disease or insects to ultimately kill the tree. For example, Thomas and Agee (1986) reported in a study at Crater Lake that tree mortality (for trees larger than 7.9 inches dbh) in unburned sites was 10 percent for sugar pine versus the burned sites where there was 36 percent mortality of the sugar pine.

Dealing With Duff in Old Growth Ponderosa Pine

There are a variety of factors to consider in choosing appropriate management techniques for minimizing large tree mortality in old growth ponderosa pine sites when deep duff is located at the base of the tree (fig. 9.5). Foremost, the sensitivity of the site (in terms of environmental concerns, recreational user conflicts, etc.) can influence the best approach to use when conducting treatments in places reflecting old forest conditions. If a site such as a campground is highly visible to the public, or the goal is to minimize tree mortality, it may be advisable to take a conservative approach in restoration efforts. In many cases, it is the initial entry into an old ponderosa pine stand that requires additional consideration and care. Once fire is introduced and the frequency reflects a more historical range, these extra steps may no longer be needed. If this is recognized as being sensitive and mortality is a concern, addressing a few key elements can aid in determining which set of treatments are most appropriate given the particular circumstance. Following is a decision-tree to aid in identifying the most likely set of treatments (fig. 9.6).

Do the bases of the large trees have substantial duff consisting of bark slough (>5 inches) (fig. 9.6)? If roots are not present, then raking the duff away from the base is needed to avoid smoldering and potential killing of the cambium. Remove duff at least 9 inches away from the tree base by light raking (lawn rakes are wide and remove most material quickly) or if the site is dry, a leaf blower may be a good tool (Hood 2010).

Figure 9.5. Deep duff from bark slough in ponderosa pine.

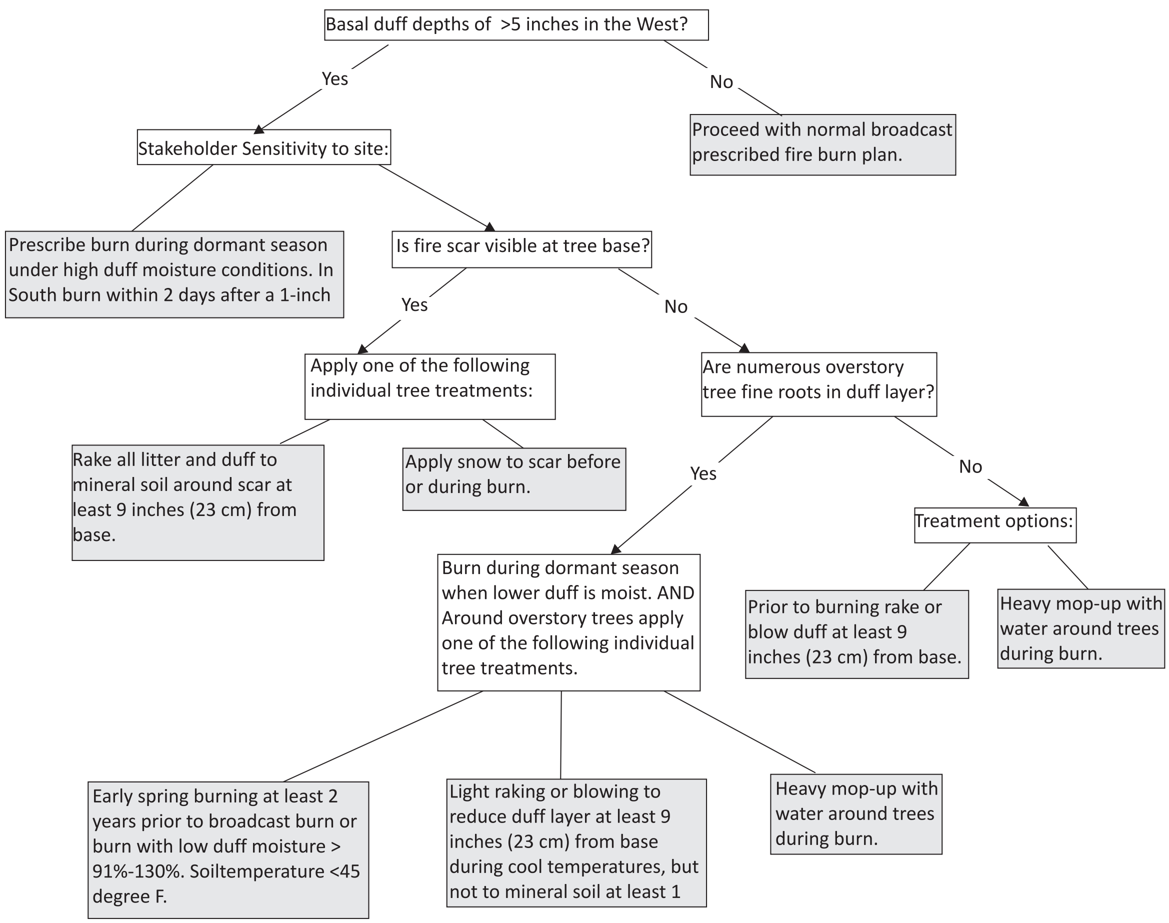


Figure 9.6. A decision process to determine if other alternatives should be implemented in minimizing mortality in old ponderosa pine (figure modified from Hood 2010).

Are there fine woody roots in the duff, close to the mineral soil and throughout the lower duff? If roots are present (particularly just above the mineral soil) treatments will be needed to address two factors: diminishing smoldering of the duff that may kill the cambium and conducting treatments when the roots are the least active. Roots are most active before bud burst and through the growing season (Pregitzer 2003).

The first objective is to alter the environment so as to force new roots to grow in the mineral soil rather than in the duff. Secondly, it has to occur when the roots are not active and the tree is dormant (fig. 9.7). All treatments should occur when soil temperatures range between 38 and 45 °F (early spring or late fall) when the tree is dormant and roots are the least active. In recent studies we noted that it takes a minimum of two years to notice changes in root location where roots are primarily in the mineral soil and not in the duff. Treatments can be incorporated into a broadcast burn of the site as long as temperatures are cool; it does not require single tree treatments.

If the area is large and conducting treatments around individual trees is impractical, yet minimizing tree mortality is an objective, then the introduction of fire may need to be completed in multiple entries. The initial entry may be used to blacken the surface to enhance decomposition and to only remove a portion of the duff. High levels of moisture in the duff will minimize smoldering potential. Smoldering is minimal when the lower duff holds greater than 100 percent moisture content (up to 130 percent) in protected areas. The deep duff layers may have as low as 90 percent moisture content on more exposed locations. It may take up to three burns (three consecutive years) to prepare the site for a fall or late-summer prescribed fire.

Mechanical removal: Raking the material away from the tree bole works well when smoke issues are of concern such as smoke impact zones or when the burn window is such that it prevents prescribed burning (see Chapter 8). The objective is to remove

Figure 9.7. Fine woody roots in deep duff that is greater than 5 inches.

most of the needle and duff mat, but not all the way to the mineral soil (thus it may be effective to leave approximately one inch of duff above the soil surface). Treatment still requires installation when soil temperatures are low, but the lower duff moisture is not a required criterion. This provides opportunities for fall and/or spring treatment implementation. Preferred tools will vary depending on situation, however; tools of choice include leaf blowers, garden rakes, fire rake, or McClouds (fig. 9.8).

Prescribed fire: When using prescribed fire, an additional criterion is lower duff moisture content. Lower duff moistures ideally would average 85 to 130 percent moisture content when fine roots are present. Experience has indicated that on southerly facing aspects lower duff moisture content can vary from as low as 50 percent (on exposed areas on the downhill side of the tree on steep slopes) and as high as 150 percent moisture content in shaded and protected areas (uphill side of tree) with average moisture content being about 88 percent. If the consumption is insufficient to remove some of the duff, it may need to be repeated within two years (needle layers begin to build and the effectiveness of first treatment is diminished). Otherwise, if burn windows do not allow for a second implementation, a rake treatment can follow the burn treatment (fig. 9.9a).

a

b

Figure 9.8. Mechanical treatment of duff. Two options are possible: (a) remove most of the duff with a rake or leaf blower, or (b) mix the duff to enhance decomposition with a fire rake.

a

b

Figure 9.9. Prescribed fire techniques. In ponderosa pine where surface litter is dry, a drip torch was used. In areas where litter is too wet to ignite, but lower duff is <40% moisture content. The top litter layer was removed with a rake and then propane torch used to ignite duff was used. Crews called this the "Top-N-Torch."

Treatment combinations: Sometimes the upper litter layer is too wet to ignite; however, the lower duff is dry enough to ignite using a propane torch. This "top and torch" treatment involves raking the upper layer and igniting the lower layer to consume the duff when soil temperatures are cool (fig. 9.9b). Leaf blowing may or may not work and the duff may be too wet to readily be blown away, but it may be an option in certain conditions. In this situation, we have seen lower duff moistures as low as 40 percent moisture content (Theresa Jain personal communication). Another combination is to rake the fluffy material with a garden rake and remove the deep duff with a combi-tool or McCloud. A leaf blower is another option, but this only works when the upper needle and duff layers are dry (Hood 2010).

Managing Wildfire for Meeting Resource Objectives

The use of wildfire as a management tool is increasingly becoming a technique that allows large acreages to be treated. In 2009, the "Guidance for Implementation of Federal

Wildland Fire Management Policy" was enacted (USDA and USDI 2009). This updated policy gave the authority for a wildfire to be managed for multiple objectives. Basically, a section of a wildfire can be allowed to burn to meet resource objectives while another section of the wildfire could be suppressed. This allows naturally (in other words lightning) ignited wildfires to burn in landscapes that once had fire as a major ecosystem disturbance, as long as the impacts were within limits determined beforehand. In order to allow a wildfire to burn as a management tool, the land agency unit must go through a planning and analysis process, identifying areas where this practice is permitted, and determining acceptable fire behavior and effects. This analysis is currently performed in the Wildfire Decision Support System (WFDSS). This policy allows fire managers to use wildfire as another cost-effective management tool to aid in the restoration of fire on the landscape during favorable burning conditions. There are a tremendous amount of acres that need treatment across the West. The use of wildfire is another tool that can move us toward the treatment of large acreages. Implementing these types of fires requires planning and acceptance from line officers, resource specialists, and the public.

Manager comment: The Land and Resource Management Plan along with the Fire Management Plan establish the resource objectives and goals in which to address multiple resource objectives for a given incident. Not only can some portions of a given fire have different objectives but these objectives can change as the fire burns across the landscape. Long duration, multiple objective fires are truly the best approach for managing federal lands as the fire process will influence vegetation structure and composition.

Conclusion

The objective of this chapter was to introduce many of the elements associated with the use of prescribed fire. Some may be unfamiliar to those who recognize the value of prescribed fire but do not necessarily understand the complexity associated with implementation. Other sections focus on unique situations that may require a different approach. The managers' comments interspersed throughout the chapter demonstrate that use of prescribed fire requires experience and knowledge, and the greatest lessons come from working alongside experienced practitioners.

Further Reading

The following suggested readings are guides, syntheses, and information that provide details concerning prescribed fire or unique situations.

Hood, Sharon M. 2010. Mitigating old tree mortality in long-unburned, fire-dependent forests: a synthesis. Gen. Tech. Rep. RMRS-GTR-238. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 71 p.

Kilgore, Bruce M.; Curtis, George A. 1987. Guide to understory burning in ponderosa pine-larch-fir forests in the Intermountain West. Gen. Tech. Rep. INT-233. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 39 p.

Thomas, Terri L.; Agee, James K. 1986. Prescribed fire effects on mixed conifer forest structure at Crater Lake, Oregon. Canadian Journal of Forest Research. 16(5): 1082-1087.

Wade, Dale D.; Lunsford, James D.; Dixon, Merlin J.; Mobley, Hugh E. 1989. A guide for prescribed fire in southern forests. Tech. Publ. R8-TP 11. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 56 p.

Weir, John R. 2009. Conducting prescribed fires: a comprehensive manual. College Station, TX: Texas A&M University Press. 194 p.

Chapter 10

Monitoring

Chapter Rationale

Monitoring was noted as a very important component in our interviews. However, time, people, and expertise were always limiting monitoring efforts. The motivating questions that guided this chapter are:

- What are the elements to consider when developing a monitoring plan?
- What methods are preferred when developing a monitoring plan?
- Do methods have to be quantitative or can qualitative methods be used?

Introduction

Monitoring is an oft-neglected yet critically important component of the fuel management cycle. Skillfully implemented, it can facilitate manager and stakeholder review of and modifications to both entire fuel treatment programs and the formulation of particular prescriptions (Derr and others 2005). It can also be an effective way to communicate to stakeholders and resource staff about the desired forest conditions that result from thoughtfully designed management. Data from monitoring can be used to characterize a baseline, or frame of reference, against which treated stands can be compared when forest conditions are assessed both before and after applying treatments and, when the opportunity arises, after a treated stand is encountered by a wildfire.

One theme that emerged from manager interviews was a strong connection between commitment to monitoring and presence of a vigorous fuel treatment program. This is perhaps either because commitment leads to formal feedback and, ultimately, a more effective fuel treatment program, or because where there is an active commitment to fuel treatment, sufficient resources are dedicated and monitoring becomes a compelling component to ensure that the investment in fuel treatments pays off.

Another emergent theme was that local, long-term (>5 years) knowledge of the area and length of fuels management experience were key determinants of fuel treatment success. Understanding the site-specific nuances of fire weather, the type of fire behavior to expect in a prescribed fire, and the dependence of post-fire outcomes on prescription parameters is most commonly obtained by experiential learning and is often specific to a local context. Connecting this local, experience-derived understanding with information gained from monitoring offers an opportunity to reach a deeper and more nuanced understanding of subtle variations in treatment outcomes. For example, such connection could answer the question of how a fire prescription influences fuel consumption as a function of duff moisture content and wind speed in a particular kind of forest structure and topographic setting.

Formal monitoring, and the knowledge it can inform, is especially important given that mentoring opportunities are increasingly scarce as tight budgets and high workloads decrease the frequency with which new managers work side-by-side with seasoned practitioners. Unbiased, local monitoring information, correctly interpreted, offers another path to better fit fuels management practices to achieve the objectives for an area of interest. Preferably, the anecdotal knowledge of local, experienced managers can be tapped for these interpretations to provide even better, context-specific predictions of potential treatment effects. Monitoring information processed in this way represents a critical resource for current and future decision-makers responsible for designing and carrying out landscape-scale fuels management programs.

Developing a Monitoring Plan

Several standardized but elaborate monitoring protocols have been developed (for example, FFI: software tool for ecological monitoring [Lutes and others 2009] and FireMon: Fire effects fire monitoring system [Lutes and others 2006]); however, these may not be ideally suited as templates for generating the timely monitoring data needed to support the previously outlined objectives. Derr and others (2006) offered a question-driven recipe for formulating a customized, targeted, relevant, and concise monitoring plan. Focusing on addressing a few key questions ensures that the right information is collected to efficiently address specific objectives.

Question 1: *What are the project objectives and goals?*

The Purpose and Need section of the typical National Environmental Protection Act document is a useful point of departure for managers in Federal agencies. Managers in state agencies and other organizations seeking guidance may look to institutional documents that detail corporate fuels management objectives and consider the local ecological, geographic and social context.

Question 2: *How will the monitoring information be used to adapt future prescriptions so that they are more successful? How will monitoring information obtained after a disturbance such as a wildfire be used to guide future management activities?*

Considering these questions is essential; answering them can provide a basis for choosing what to monitor and ensuring that monitoring insights will drive adaptations to management and future monitoring. In the process of answering the questions, the best methods may emerge in terms of: (1) addressing the objectives and goals associated with implementation (did the project do what it said it would do?); (2) ensuring effectiveness (did the project achieve the goals?); and (3) validation (were initial assumptions justified, considering the outcomes?).

Question 3: *What will be monitored?*

Thorough efforts to address Questions 1 and 2 will typically define the list of what should be monitored. However, continuous attention is often needed to ensure focus—it is easy to think of additional information that, if collected, could be interesting or useful, but past experience suggests that adding unnecessary items into a monitoring plan can lead to a daunting data collection protocol or sampling design. Monitoring efforts can then fail due to complexity and cost, and the information required to address Question 2 is never captured.

Question 4: *How much will monitoring cost, and who will pay?*

Often, this question is considered at the end of the monitoring design process—that is too late. Budgets dictate what kind of monitoring is possible, and as design efforts invariably entail choices among alternative approaches, budget considerations play a crucial role in making choices. Thus, availability of expertise, time, and financial resources must be considered up-front. It is also reasonable to anticipate some adaptation occurring as monitoring prospects are explored. In addition, the information needs of multiple stakeholders may present opportunities to garner additional monitoring resources when efforts are coordinated.

Question 5: *How will monitoring be accomplished?*

This question covers numerous technical aspects of the effort, including decisions about when data will be collected (for example, interval and time of year), where data will be collected (for example, sampling density and plot size), and how many repeated measures will be needed to address Question 2. This is where sampling theory and statistical considerations become crucial.

There are four ways to collect data: census, mapping, non-statistical (for example, convenience) sampling, and statistical sampling. A census assesses every individual in a population, just as the U.S. census attempts to count 100 percent of U.S. residents. Mapping, typically implemented as the compilation of data using geographic information systems or remote sensing, produces results that appear similar to those of a census; however, the mapping methods are founded on classification, modeling, or both, and these are inherently scale dependent. Consequently, the result is not a true census and any particular indicator of interest may or may not be well represented. Non-statistical sampling, sometimes termed convenience sampling, occurs when subjective choices affect the when, where, or what of sampling and where different choices by different individuals would yield different results. Statistical sampling occurs when data are collected from a representative sample (i.e., every unit in the population has an equal probability of being selected). However, the detail and extent of sampling is often dictated by time and money. Moreover, some of these methods can be combined—for example, generating maps from a convenience sample and validating map classifications using another ground based sample. (See the Monitoring Design section for further details.)

Question 6: *Who will do the monitoring?*

Answers to this question have implications for quality assurance and data consistency, data management, and training. For example, it is often helpful to have one person on a data collection crew act as the crew leader. Also for consistency, it is ideal to have the same group of individuals involved in data collection, particularly when estimates involve judgments that may be subjective (for example, ocular estimates of percent cover, exposed mineral soil, or vegetation). The value of solid training tools and protocol guides in enhancing data quality and reducing variation among observers cannot be overestimated, and some such tools have already been developed.

Question 7: *When and where does the monitoring need to occur?*

The answer to this question depends on the goals and objectives of the monitoring plan. Typically, two types of monitoring are of interest: (1) evaluation of treatment implementation and (2) assessment of treatment effectiveness.

Evaluating implementation: for prescribed fire, treatment implementation occurs if, and only if, a burn would be within prescription (for example, with respect to fuel moisture, humidity, wind speed, and direction). Waiting for the right burn window can take months to years, so obtaining pre-treatment monitoring data can be more challenging than is generally understood. When a prescribed fire is a “go,” there is rarely time to get a monitoring plot installed. However, if a monitoring plot is installed and it takes years to get the right burn window, the monitoring plot data may no longer be representative of conditions (due to vegetative growth) when the treatment takes place. One technique to address this challenge is to compare treatment outcomes to baseline information. Reference conditions are sometimes used as baseline information, and photograph points with data can be considered a reference condition.

Treatment effectiveness: the best, truest test of treatment effectiveness is to have a wildfire burn through the treatment. Ideally, treatment effectiveness would be determined by comparing change in plots established before a fire on treated and untreated land with re-measurements of those plots following fire. Because the time and place of a fire disturbance is rarely known in advance, conducting pre-disturbance measurements is problematic and most instances in which pre-treatment data are available depend on the serendipity of existing, systematic, permanent forest inventory plots. However, it is expensive to have a pre-existing grid of plots distributed across the landscape at sufficient density to capture the results of a particular event, and the Forest Inventory and Analysis (FIA) grid density is so low that only very large fires are likely to have a sufficient plot sample. Unless fuel treatments become much more widely implemented than they are today, the number of inventory plots located in fuel treatments will be miniscule. However, there are examples of fuel treatment effectiveness evaluations in dry mixed conifer forests in the western United States that either quantify post-fire outcomes as a function of pre-wildfire forest structure or that use information from a reference condition (untreated sites) to compare against the prescribed fire and wildfire outcomes (Fulé and others 2012; Graham and others 2009; Jain and others 2007; Lyons-Tinsley and Peterson 2012; Moghaddas and Craggs 2007; Prichard and others 2010; Ritchie and others 2007; Safford and others 2009, 2012; Wimberly and others 2009).

Question 8: *Where will monitoring data be stored, archived, and documented?*
The logistics of maintaining data are very important to consider prior to conducting any monitoring, especially given the sometimes long intervals between data collection and the need to conduct analysis (for example, not until a fire occurs). It is not uncommon for monitoring of one plot (depending on location, protocol detail, etc.) to cost in excess of $3500; therefore, taking time to ensure data integrity, security, and accessibility over time is critical. The data have to be: (1) accessible to managers and researchers; (2) archived in stable formats on stable media (for example, at Missouri Breaks, data collected in the field are archived in an ASCII format), which can be imported into almost any current and, hopefully, future software environment; (3) resistant to corruption and accidental destruction; (4) accompanied by detailed metadata containing sufficient descriptive information about the data and their collection that others can use to interpret the data, possibly for purposes beyond what was initially envisioned; and (5) stored and archived as corporate data backed by a long-term information management commitment.

Question 9: *How, when, and by whom will monitoring data be analyzed?*
Analysis should be considered at the same time as Question 2. Ideally, when monitoring is an interdisciplinary enterprise with multiple constituencies, there will be multiple analysts representing a range of disciplinary expertise with a stake in analyzing the data to address different questions. If data are publicly available, there can be entire networks of university and agency research analysts that may be interested in exploring the data. However, fuels managers must plan and budget for analysis of monitoring data that leads to better fuels management in the future, and assign sufficient priority to ensuring that it happens routinely if the investment in monitoring is to produce the promised payoff. Some of this may be accomplished via collaboration with research networks, but building at least some analysis capacity in-house will likely lead to more timely results and provide the flexibility to employ exploratory analysis that ultimately addresses a broad range of questions about treatment effectiveness and efficiency.

Question 10: *Is the monitoring plan well designed?*
Any monitoring plan can benefit from review and refinement, and if people familiar with monitoring protocols (such as a monitoring coordinator or an academic or consultant expert) are encouraged to provide critical feedback that will be used to improve the plan, the chances for successful monitoring are increased. The monitoring plan may also be more widely applicable and can be picked up to support monitoring work at other locations. Remember, the more important the project, the more important it is to

devote sufficient time and money to design an effective monitoring plan, even before the first treatment is implemented.

Two Phases of Monitoring

It is critical to remember that there are essentially two phases of fuels management outcomes being addressed: one is short term and one will likely take much longer.

The short-term questions at the local or stand scale are centered on how the fuel treatments performed:

- Were surface fuels reduced by as much as expected?
- Was canopy base height elevated to the level called for in the prescription?
- When predictive models such as FFE-FVS are run with pre- and post-treatment plot data, have key hazard criteria such as probability of crown fire, surface flame height, and mortality volume generally moved in the desired directions?

Medium-term questions at this scale center on fuel treatment longevity and require information about tree establishment and growth rates, growth response of advanced regeneration, and rates of surface fuel accumulation. At the landscape scale, short- to medium-term questions might address not only the sum of the stand-level results but may also consider whether the spatial pattern of reduced hazard is likely to produce significant changes in fire regimes:

- Will large fires be less common?
- Will the WUI be less threatened?

Landscape fire modeling software such as FSPro, FARSITE, and FlamMap may be helpful in evaluating landscape benefits of treatments as they accumulate over time as more land undergoes treatment and as the effectiveness of older treatments diminishes (Appendix B).

How treatments perform when a fire encounters them (and how untreated acres respond to the same fire) is, by nature, learning that can only occur over a longer period of time as more and more treatments are eventually visited by wildfire. Managers have no control over when this will occur, so patience and consistency in monitoring implementation are crucial. While the full benefits of this kind of monitoring information may be some years away, delaying the start of this kind of monitoring is truly short-sighted and assures that the benefits are even further delayed.

Short-term, stand-level monitoring data (pre- versus post-treatment) can be of substantial value to managers to provide near-immediate feedback that can be incorporated into next season's fuels management activities. For example, if surface fuel reductions are not being realized as expected, the reasons can be investigated and remedies or different prescriptions can be explored. The immediate utility of this monitoring data calls for building capacity within the management organization to not only collect but also to analyze monitoring data covering this phase. The short- and medium-term, landscape-scale evaluation of how treatments are working is the only way to know if the hundreds of activities on the ground are adding up to the more resilient landscapes that are the goal as well as increasing safety for people and property. While the field organization is best situated to collect the monitoring data, there may be value in partnering with research organizations or enterprise teams as well as other agencies and landowner groups to carry out analysis collaboratively at this scale.

There are also more long-term questions:

- How well do treatments work when burned?
- Which treatments best promote resilient forests?
- How do the treatments affect carbon storage?

These types of questions do not lend themselves to immediate, definitive answers. The variability in our forests (structure and topography) and in the fire weather that controls fire behavior means that large samples are required to develop statistically significant findings. Over even the 5- to 10-year career of a fuels manager, it would not be typical for more than a handful of treatments to be encountered by fire, and the sample would probably not be large enough to support conclusive interpretation. So, while the fuels manager can learn something opportunistically from such anecdotal evidence, the full power of monitoring data is only realized when a sizable store of statistically representative monitoring data has accumulated and can be analyzed while controlling for such sources of variation as stand structure, type of treatment, and fire weather. Thus, addressing this class of questions becomes a shared mission to which everyone in an organization contributes, and capacity to address such questions increases over time. For monitoring data to effectively inform such inquiries, it is essential that protocols remain consistent over time; monitoring plots are revisited to periodically update data as vegetation regrows or new disturbances occur; and good records are kept on what treatments were implemented, at what locations, and at what times.

Elements of a Monitoring Design

Monitoring to evaluate the implementation: did the project do what it said it would do?

Evaluation is completed either with measurements of pre- versus post-treatment conditions or by using a reference condition as a baseline compared to the post-treatment conditions. Using the reference condition can be an acceptable alternative when it is not feasible to complete a pre-treatment measurement. Reference conditions can be the current condition or desired future condition—the key is that the reference condition provides a basis against which the treated condition can be compared. Features selected for measurement should relate to the elements identified as fundamental to the desired future condition.

Monitoring to evaluate effectiveness of treatment: did the project achieve what we wanted to accomplish (meeting objectives)?

Some parts of monitoring focus on indicators that are long-term and generally more ambiguous. The effectiveness of a treatment can only be truly evaluated when there is a response to observe. But in the case of response to a wildfire, measuring the effectiveness of the treatment after a wildfire burns through it usually entails years to decades. Typically, effectiveness monitoring will yield short-term results for only a tiny subset of the locations where it is attempted (for example, when fire burns through a treated stand that contains an FIA or other monumented, or physically marked, inventory plot).

Validation monitoring: were the assumptions correct? Are the objectives being met?

Validation typically requires a combination of implementation and effectiveness monitoring. It is difficult to validate the assumptions without these two elements. For example, if a fuel treatment is never burned in a wildfire, it is difficult to validate whether the treatment truly altered fire behavior. Often, people use simulation models to offer some level of face validation; however, simulation models have their own assumptions, which may or may not be valid for a given scenario.

Sampling

Even the best-intentioned monitoring effort will not meet the intended objectives if not preceded by adoption of a statistically sound sampling design and a long-term commitment from management to a sustained monitoring effort. If monitoring will be location based, where should plots or photo-points be established? When will data be collected and what attributes should be included? These key questions relate to the representativeness of monitoring findings, the precision with which effects can be assessed, and the spatial and temporal resolution of insights obtained from monitoring.

Non-Statistical Sampling

When there is no budget or sustained commitment to support monitoring, managers interested in assessing whether objectives were met have been known to fall back on what is sometimes described as a "convenience sample." Visual inspection on a walk-through of a treatment area, "drive-by" observation or "windshield surveys" that may serendipitously fit into other scheduled work, and after-action review reports derived from such efforts are examples of non-statistical sampling that can cheaply provide limited information on treatment outcomes. However, benefits are quite restricted relative to what is possible with a genuine, statistically based process.

Interpretation of treatment effectiveness will vary among observers, and there may be no reliable way to effectively and systematically communicate what is learned to others. Information quality and detail are typically insufficient to inform adaptive management, and the information is inherently biased ("sample" is concentrated along the road or in the areas easily accessible in a walk through). There is no known precision (or confidence) that can be associated with the information, and the reliability of the assessment is sacrificed. There is also no assurance of long-term continuity that is critical for assessing treatment effectiveness in the event of a fire—with no formally established points on the ground, how can fire effects be related to post-treatment conditions? Hopefully, these limitations underscore the importance of undertaking a statistically supported monitoring framework.

Manager comment: While it's recognized that this type of monitoring isn't statistically rigorous, the return to a site with the interdisciplinary team and other implementers through time has helped with self-learning and adaptive management within the team. It helps demonstrate and educate resource specialists not directly involved with fuels about the various impacts of fuel treatments.

Statistical Sampling Principles for Monitoring

We discuss two types of statistical sampling: point-based, which is primarily tied to repeated observations of a location using photographs; and plot-based, which is based on measured attributes on field plots. Three monitoring concepts are fundamental to both types of sampling: experimental unit, replication, and independence.

The experimental unit in the case of monitoring is the treatment unit, which is the smallest area for which a treatment is applied—it may be a single stand or a collection of similar stands receiving the same treatment, and it need not be spatially contiguous. Ultimately, measurements from all samples in that unit can be averaged together to generate a composite value for that experimental unit representing a single sample from the larger population of forested land.

To ensure the statistical replication that is required in order to assess precision (provide confidence intervals around estimates), multiple samples (treatment units) are needed for each treatment type. Ideally, the more replication of a treatment, the better. However, time and money limit the number of treatment units that can be assessed; therefore, a minimum of three replicates of the treatment unit is recommended, as three is the fewest treatment units that could be sampled and still provide the information needed to generate confidence levels around the estimates.

Terminology

A confidence interval is the upper and lower boundary of an interval that contains a population parameter at a pre-specified level of probability (confidence level)—note that given a level of confidence, for example 95 percent, a larger data sample will typically reduce the error estimate and narrow the confidence interval.

Treatment units included in the sample for a treatment type need to be independent, meaning that what happens on any one treatment unit will have no influence on any other treatment unit. In the simple case of equal-sized units, each should have an equal probability of being selected as part of the sample. Making a list of all units where treatment X is applied, numbering them, and rolling a dice or using a random number generator to choose units in which to install monitoring sites ensures independence. Where treatment units are of different sizes, random selection can still be made using area weighting.

Point-based sampling relies on photographs taken at specific points within a fuel treatment, at different times, to detect changes in vegetation and soils. Repeat photography requires that camera position and orientation with respect to the photo-point are constant throughout the monitoring period. One way to fulfill this requirement is to set up permanent markers for the photo-point and camera location. Hall (2001a, 2001b) provided an excellent handbook, based on 45 years of experience, that covers the principles of repeat photography and photo-point sampling. It includes data forms and information about techniques, equipment, and analysis. Hall suggested that before points are set up, the monitor should consider five basic questions: why, where, what, when, and how.

- Why are you monitoring?
- Where is the best location to set up the photo-points that will answer your monitoring questions?
- What are the variables you want to monitor?
- When and how often should you take pictures?
- How detailed do the data need to be, and must they be quantitative or will qualitative data be sufficient?

Plot-based sampling is familiar to most managers, many of whom may have had experience assessing timber cruise plots such as those used during timber sale preparation or stand exams. Plots can be and frequently are used to characterize and describe vegetation characteristics relevant to fire and fuels such as tree size and density, canopy base height, composition and abundance of forest understory, soil cover characteristics, and tree height. Transect-based sampling is a kind of sampling that is often used on field plots to characterize loadings of down woody fuels (for example, Brown 1974), though it is potentially suitable for sampling any kind of linear features (for example, at the right scale, roads, and trails). However, for predicting fire behavior and effects, photo-series and expert characterization of the surface fuel model (via Albini 1976; Riccardi and others 2007b; Scott and Reinhardt 2001) have greater power. Borrowing inventory design elements from other field-tested inventory and monitoring systems such as FIA, Forest Health Monitoring or the various fire monitoring protocols as a starting point is a time-honored strategy with the potential to leverage previous investments in statistical design, field guide language, data recorder software development, and database design (including quality assurance checks and calculated variables). The prudent manager will be selective about which attributes are included to ensure that the data collected will align with monitoring objectives and that the implementation can be accomplished with available budget, field personnel, and computing resources.

Due to sampling variability, which in typically heterogeneous, dry mixed conifer types is usually much greater than for forest plantations, monitoring data will have the greatest power under a system of permanent plot locations that are remeasured at appropriate intervals (for example, immediately pre- and post-treatment, after significant regrowth has occurred, and immediately post-fire [FIA grid is an example]).

Model-Assisted Monitoring

Collecting plot data that can be modeled in FFE-FVS offers some significant advantages. This model can predict many fire and fuels-relevant attributes. While accuracy of model predictions may vary depending on the scenario, such models are typically more robust when used to assess differences—for example, among treatments or between pre- and post-treatment conditions. Moreover, this model can accept a remarkably diverse array of plot data types, so one is not locked in to fixed or variable radius plots of any particular size, and plot design can be tailored to available resources.

As we learned in Chapter 5, modeling fuel treatment effectiveness is easy to do in Forest Vegetation Simulator (FVS)—as long as the modeler and manager have a clear vision of: (1) what constitutes a hazardous condition, (2) what constitutes hazard reduction, (3) which kind of hazard reduction is most important, and (4) model assumptions. Also, if the goal is to use the model to determine fuel treatment longevity, then calibrating the growth rate is suggested. Plot data can then be converted to frequency distributions of the kind found in Appendices A and C, where one can look at a characteristic (for example, mortality volume under severe fire weather or indices of crown fire potential) over the entire landscape, or for any subset, such as the places under consideration for fuel treatment in the coming year (if such pre-treatment monitoring data are readily available). Then, if treatments are modeled in FVS, their outcomes, in terms of mortality volume or any other fire- or fuels-related trait, can be predicted along with other useful information such as net treatment cost and post treatment stand attributes. When combined with post-treatment monitoring and, ultimately, post-disturbance monitoring, there is the advantage of a reality-check on the modeled outcomes. But even absent post-disturbance modeling, this kind of monitoring/modeling database is a powerful tool for exploring assumptions, alternatives, and likely outcomes and can help identify opportunities to accomplish the greatest fuel treatment impact for the lowest cost.

Conclusion

A commitment to monitoring reinforces a commitment to active fuels management as it can lead to a more effective and efficient fuels management program. Just as a clear and shared understanding of fuels management objectives is critical to the success of a fuel treatment, clear and focused objectives for monitoring are essential to ensure that investments in monitoring produce results in terms of useful and timely information that improves the effectiveness and efficiency of the fuels management effort. Time spent on monitoring design is well spent if it leads to clear objectives and a focused, results-oriented monitoring protocol that can be sustained over time, even as responsibilities for data collection, management, and analysis are transferred among individuals. Informal, non-statistical, "windshield surveys" are no substitute for thoughtful, carefully planned, consistently implemented, and adequately funded (over the long-term) monitoring. Although managers often have insufficient time to become proficient with models such as FFE-FVS, models have the potential to supplement monitoring data with effectiveness predictions and provide key insights that could improve fuel treatments. Analytic capacity can be brought to bear via partnerships, collaborative agreements, and enterprise teams. Cooperative arrangements may also be useful to periodically and opportunistically evaluate treatment effectiveness when wildfires encounter treated stands.

Further Reading

A variety of monitoring protocols are available that focus on fire effects, soils, wildlife, and other elements. However, new information and protocols are continually being developed; therefore, we provide just a view examples of what is available. (See Appendix B: Decision support tools for managers.)

FEAT/FIREMON (FFI) (A monitoring software tool designed to assist managers with collection, storage, and analysis of ecological information.)

Forest Health Monitoring Program, U.S. Department of Agriculture, Forest Service. (A national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis. The program uses a variety of approaches to address forest health issues that affect the sustainability of forest ecosystems.)

Forest Inventory and Analysis National Program (FIA). (Reports on status and trends in United States Forests.)

Hall, Frederick C. 2001a. Photo point monitoring handbook: part A–field procedures. Gen. Tech. Rep. PNW-GTR-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1-48.

Hall, Frederick C. 2001b. Photo point monitoring handbook: part B–concepts and analysis. Gen. Tech. Rep. PNW-GTR-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 49-134.

Lutes, Duncan C.; Benson, Nathan C.; Keifer, MaryBeth; Caratti, John F.; Streetman, S. Austin 2009. FFI: a software tool for ecological monitoring. International Journal of Wildland Fire 18: 310-314.

Lutes, Duncan C.; Keane, Robert E.; Caratti, John F.; Key, Carl H.; Benson, Nathan C.; Sutherland, Steve; Gangi, Larry J. 2006. FIREMON: fire effects monitoring and inventory system. Gen. Tech. Rep. RMRS-GTR-164-CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

Soil Quality Monitoring for Long Term Ecosystem Sustainability on Northern Region National Forests (SOLO). (Focused on monitoring soil disturbance and includes documents on how to conduct a rapid assessment of soil disturbances (Volume 1 and Volume 2). Soil-disturbance field guide and associated forms.)

Vesely, D.; McComb, B.C.; Vojta, C.D.; Suring, L.H.; Halaj, J.; Holthausen, R.S.; Zuckerberg, B.; Manley, P.M. 2006. Development of protocols to inventory or monitor wildlife, fish, or rare plants. Gen. Tech. Rep. WO-72. Washington, DC: U.S. Department of Agriculture, Forest Service. 100 p.

Section III. Reality Check: The Economics, Feasibility, Longevity, and Effectiveness of Fuel Treatments

Chapter 11

Inventory and Model-Based Economic Analysis of Mechanical Fuel Treatments

Chapter Rationale

Several key questions guided our analysis, including:

- What is the scope of the fuel management challenge in the dry mixed conifer types of the northern West? How many acres should be classified as high hazard based on the likelihood of crown fire, high surface flame height and/or high rate of tree mortality?
- How do these high hazard characteristics compromise the health of post-fire forests and/or negate ecosystem functions such as long-term carbon storage benefits?
- Can silvicultural manipulation reduce fire hazard while retaining viable, resilient forests? If so, how many acres would benefit from treatment?
- What fuel treatment approaches are likely to be both effective and economically feasible (e.g., be self-supporting) in reducing fire hazard?
- How do the answers to the above questions vary among forest types and sub-regions in our study area?

Introduction

In this chapter, we evaluate the feasibility of conducting fuel treatments within our synthesis area. We cannot assume it is possible to implement a fuel treatment in every place that would benefit from one, and there are many kinds of fuel treatments, only some of which will be effective in any particular stand. There are many stands where no fuel treatment is likely to be effective and many more where an effective treatment will be more costly than it is worth. We use the Forest Inventory and Analysis (FIA) BioSum framework to assess the effectiveness, costs, and potential returns from generic, multi-purpose mechanical fuel treatment approaches commonly implemented in this region. For effective treatments, we describe treatment costs, yields, and gross revenues associated with merchantable and energy wood; costs of transporting wood to mills and bioenergy facilities; and net revenues (or costs) of treatment operations. Results in this chapter and in Appendix C are presented by the same sub-regions and broad forest type groups introduced in Chapter 5 to facilitate localized application of the information in this synthesis.

Silvicultural simulation using the FIA BioSum framework is ideally suited to answering these types of questions. The model can assess a large, statistically representative sample of the entire forested landscape in the dry mixed conifer region, including all forest types, forest structures, ownership classes, and degrees of accessibility (for example, slopes, distance from roads, and distances to sawmills and

FIA BioSum

Forest Inventory and Analysis Biomass Summarization System (FIA BioSum) is an analysis framework that combines forest inventory data representing an analysis region, a treatment cost model, a fuel treatment effectiveness model, and a raw material hauling cost model to explore alternative landscape-scale treatment scenarios that achieve a variety of management objectives.

bioenergy facilities). FIA BioSum produces statistically reliable summaries of the proportions of the forested landscape in the dry mixed conifer region that would respond positively to treatment. The system can also estimate the costs, revenues, and product flows that could be associated with a comprehensive fuel treatment program.

Model output includes reports of the area for which each kind of treatment would make the most effective choice. Trade-offs between area effectively treated and net treatment cost can also be summarized in order to understand the effects of policies such as requiring sales of derived products to cover treatment costs.

The analysis we describe is not designed to endorse any particular fuel treatment or fuels management strategy for any given stand. Rather, it conveys a sense of the opportunities and outcomes, and range of costs and revenues over a broad, dry mixed conifer landscape, and how these vary by forest type and sub-region. Necessarily, these are inextricably linked to assumptions about treatment options, hazard concept, and effectiveness determination as well as unit costs, product prices, and existing processing infrastructure. The information presented here and in Appendix C is a useful point of reference against which to compare stands and contemplated prescriptions. Managers seeking a solution for a particular stand may find it worthwhile to run models such as FFE-FVS (Reinhardt and Crookston 2003) and My Fuel Treatment Planner (http://www.fs.fed.us/pnw/data/myftp/myftp.shtml) on sample data collected from that stand using their own assumptions to understand the potential impacts and costs of alternative prescriptions in terms that are relevant to the challenges managers face. Managers seeking to analyze entire landscapes in support of a fuel treatment management program should consider learning and using the BioSum tool that is scheduled for general release in early 2013 (software, data, tutorials, and user guide will be available at www.BioSum.info).

Although some readers may be eager to jump straight to the results of this economic analysis, results should be interpreted in the context of how the analysis was conducted, as both results and interpretations ultimately depend on the bevy of assumptions and analytical choices described in the next few pages.

Applying the BioSum Analysis Framework

The BioSum analysis framework (fig. 11.1) was developed to combine a number of data sources and models to explore alternative landscape-scale treatment scenarios that achieve a variety of management objectives (Fried and others 2005). Data sources and models include:

- systematic forest inventory data representing an analysis region
- silvicultural treatment implementation model (FVS; Dixon 2002)
- fuel treatment effectiveness model (based on outputs from FFE-FVS; Rebain 2010; Reinhardt and Crookston 2003)
- fuel treatment cost model
- raw material haul-cost model
- wood product allocation model

A variety of treatments, developed in consultation with silviculturists and fuels management experts, are simulated to assess which stands could benefit from treatment, treatment effectiveness, and net and gross treatment costs (Fried and Christensen 2004; Fried and others 2003). A series of steps are used to conduct this analysis:

1. raw materials (logs, biomass, and pulp) generated by a variety of mechanical treatments designed to reduce canopy fuels are estimated using data derived from forest inventory plots and processed via FVS (Dixon 2002);

2. treatment costs are estimated via the Fuel Reduction Cost Simulator (FRCS; Fight and others 2006);
3. gross product economic values are calculated for each product species group and size class of harvested material based on local product prices; and
4. the wood produced by fuel treatments can be summarized by species group and size class (Barbour and others 2008).

Moreover, candidate sites for building processing facilities can be simulated and evaluated with respect to economic feasibility (Fried and others 2005), or the process can use optimization to select both the best treatment for each acre and the best places to add bioenergy capacity (Daugherty and Fried 2007).

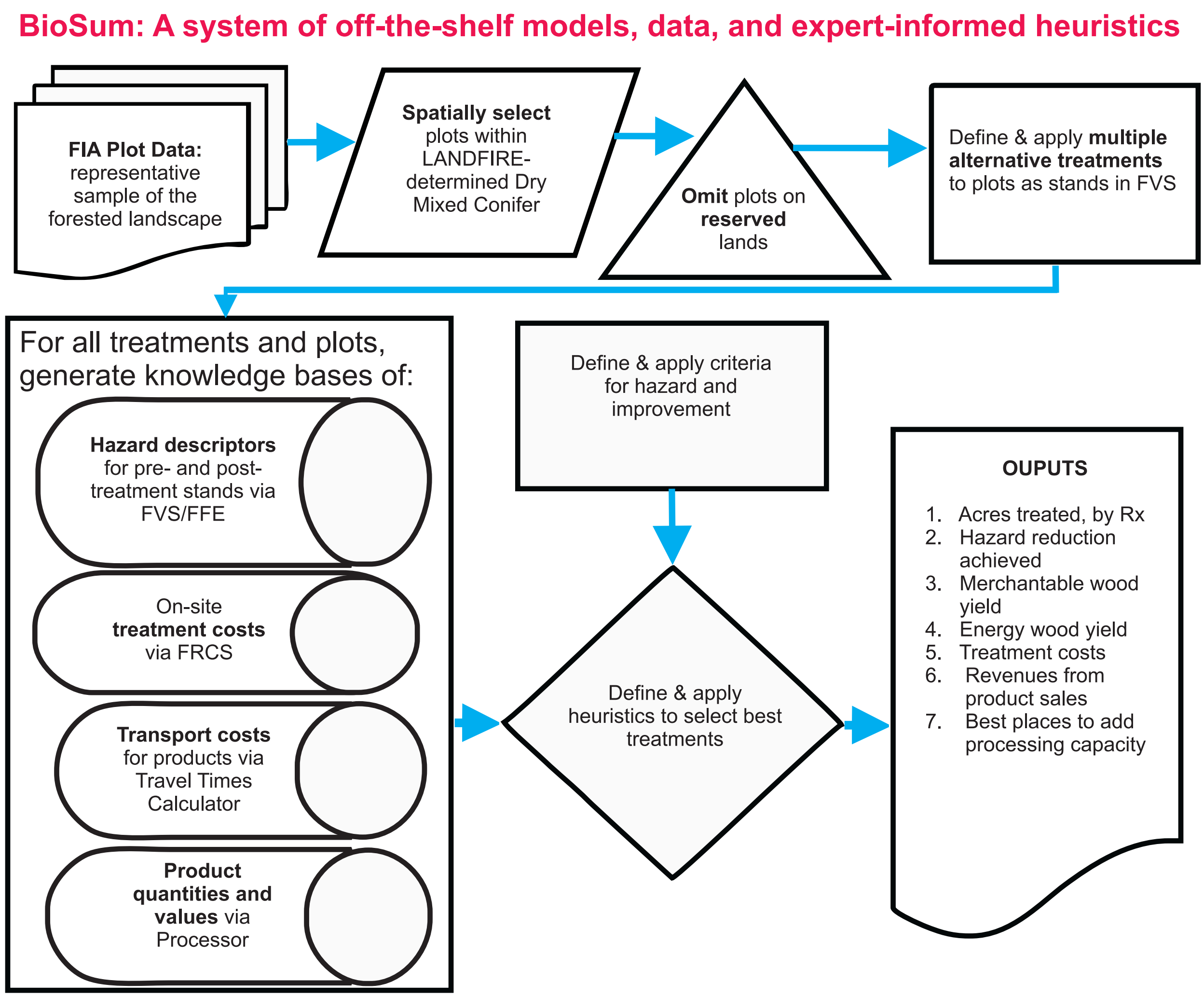
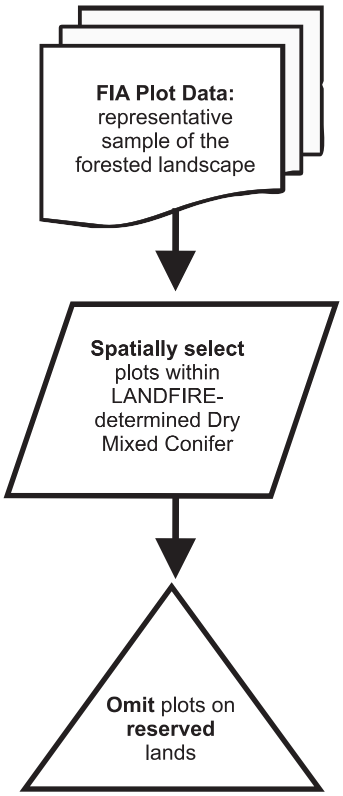


Figure 11.1. Process flow chart for evaluating the feasibility evaluation using the FIA BioSum model.

Data Acquisition and Treatment Development



FIA Plot Data

We used the forested, unreserved, condition-level data[1] from a set of 5174 FIA plots in Oregon, Washington, Idaho, Montana, Utah, and extreme northern California collected between 2000 and 2009 (described in Chapter 5). These plots were selected for this analysis via overlay of FIA plot coordinates on a grid coverage representing dry mixed conifer types derived from the LANDFIRE BpS (see Chapter 2 for details). As explained in Chapter 5, each forested condition on the selected plots was assigned a forest type group: Douglas-fir and True Fir, Pine and Western Larch, Aspen (includes birch), Western Redcedar, Non-stocked[2], or a grab bag of everything else that we call Other[3]) based on its FIA forest type[4] and a Forest Vegetation Simulator (FVS) variant based on its location (for reporting analysis results, we group FVS variants into four sub-regions; see fig. 5.1).

Model results are summarized using FIA plot expansion factors to represent acres and/or fractions of the forested landscape in each sub-region and forest type group that can be successfully treated. (An FIA expansion factor is a statistically derived estimate to interpret the number of forested acres represented by a plot.) We eliminated plots from consideration that could not be mechanically thinned without building new roads (>5000 ft from the nearest road if slope on plot was less than 40 percent; >2000 ft from nearest road if slope on plot ≥40 percent, to account for the limiting distance of cable logging). Plot data were projected in FFE-FVS to a common date of 2009 before analyzing stand attributes such as fire hazard and treatment effects. Tree list data from fixed-radius samples on these conditions include field measurements and estimates of diameter, height, crown ratio, and species, and model estimates of stem volume and merchantable and non-merchantable biomass (see Zhou and Hemstrom 2010 for details on models used).

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[1] Because FIA uses a mapped plot design in which plots are subdivided into "conditions" when there are sharp discontinuities within the forested parts of a plot (for example, in size class, forest type, stand density, land owner group, and reserve status) or when an otherwise forested plot includes non-forest area, the basic unit of analysis is condition, not plot.

[2] We do not apply treatments to non-stocked conditions, so these are not addressed in this chapter.

[3] Other includes forests belonging to one of 45 FIA forest types: Bigleaf maple, Blue oak, Blue spruce, California black oak, California laurel, California mixed conifer, California white oak, Canyon live oak, Cercocarpus woodland, Cottonwood, Cottonwood/willow, Deciduous oak woodland, Engelmann spruce, Engelmann spruce/subalpine fir, Foxtail pine/bristlecone pine, Giant chinkapin, Gray pine, Incense-cedar, Intermountain maple woodland, Jeffrey pine, Juniper woodland, Knobcone pine, Limber pine, Lodgepole pine, Miscellaneous western softwoods, Mountain hemlock, Noble fir, Oregon white oak, Other hardwoods, Pacific madrone, Pacific silver fir, Pinyon/juniper woodland, Port-Orford-cedar, Red alder, Red fir, Redwood, Rocky Mountain juniper, Sitka spruce, Subalpine fir, Sugar pine, Tanoak, Western hemlock, Western juniper, White fir, or Whitebark pine.

[4] Usually derived as the species with the plurality of stocking in the condition.

Silvicultural Treatments

Overstory treatments

Define & apply **multiple alternative treatments** to plots as stands in FVS. Drop treatments that prove unsuited.

Designing treatments for dry mixed conifer forests is challenging due to diverse topography, species composition, and tree sizes, and in some cases, the need to integrate multiple objectives. In developing generic (in the sense that they are not dependent on or tuned to initial stand conditions) treatments to model for this economic analysis, we sought to represent elements of the types of treatments that are typically considered when developing fuel treatments, meeting restoration objectives, or managing for timber production (though we did not include regeneration harvest). We developed three silvicultural treatments—two thinning treatments, a crown thinning, and a thin from below (Graham and others 1999)—and a restoration treatment (table 11.1). Crown thinning, which focused on separating overstory crowns and reducing canopy density, reduced canopy cover to 50 percent. The thin from below treatment was designed to leave all trees that were >21 inches diameter breast height (dbh) and harvest everything smaller. The objective was to eliminate ladder fuels. In the restoration treatment, we removed understory trees such as grand fir and Douglas-fir and retained ponderosa pine, western larch, and other disturbance-resilient species. At times, this resulted in an outcome indistinguishable from a regeneration harvest when disturbance resilient species were absent or present in very low densities.

Table 11.1. The six fuel treatment prescriptions modeled in BioSum can be thought of as three core, generic prescriptions with two alternative harvest system implementations for each.

Treatment name	Description
Crown thinning (WT)	Thin to 50 percent canopy cover, “good” (early seral) species cut last (assigned super low probability of removal), but Douglas-fir has equal chance of removal as white fir, grand fir, etc.; whole tree yarding, no slash disposal needed.
Crown thinning (CTL)	Thin to 50 percent canopy cover, “good” species cut last (assigned super low probability of removal), but Douglas-fir has equal chance of removal as white fir, grand fir, etc.; cut-to-length, slash disposal via pile and burn at $350/acre.
Thin from below (WT)	Leave only big (>21 inches DBH) trees, no species preferences, whole tree yarding, no slash disposal needed.
Thin from below (CTL)	Leave only big (>21inches DBH) trees, no species preferences, cut-to-length, slash disposal via pile and burn at $350/acre.
Restoration (WT)	Leave early seral species, cut everything else (including Douglas-fir), whole tree yarding, no slash disposal needed.
Restoration (CTL)	Leave early seral species, cut everything else (including Douglas-fir), slash disposal via pile and burn at $350/acre.

Harvesting method

For each of these three treatments, we modeled two automated harvesting systems to account for the surface fuels produced by harvest activity: whole tree harvesting (WT), which effectively moves tops and limbs, as well as boles, to the landing where they can be recovered for utilization (producing a minimal increase in surface fuel loading); and cut-to-length (CTL), which severs and discards tops and limbs as it processes trees to log length at the stump. For WT, we assumed that 10 percent of harvest slash (mainly limbs and tops) remained on site, and we did not apply a slash treatment in our FFE-FVS analysis. With CTL, processed logs were extracted using a forwarder, leaving all limbs and tops as slash on the site. While this reduced problems related to nutrient retention, short-term surface fuel concerns remain, particularly when a "bed" of slash is created on the trail along which equipment is operated in order to minimize soil disturbance. To account for this increased fire hazard, this treatment was followed by modeling a pile and burn treatment. While 28 percent of the slash remained uncombusted after treatment, all fine fuels smaller than 1 inch diameter were consumed according to the model.

Excluded plots

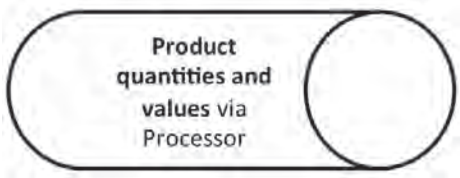
Because our treatments were designed to treat three very different kinds of forest: high overstory density, >50 percent canopy cover; stands containing remnant trees >21 inches dbh; and stands containing an abundance of fire- and disturbance-resilient species, not every treatment is applicable on every forested condition, as evidenced in modeled treatment outcomes. For example, in stands with a canopy cover of 35 percent, it is impossible to devise a crown thinning treatment that will leave a residual canopy cover of 50 percent. A condition with no trees less than 21 inches dbh cannot be treated using a thin-from-below with a 21-inch dbh maximum diameter for removed trees, and when no resilient species are present, a restoration treatment morphs into a regeneration cut. To avoid such outcomes in our modeling, we dropped treatments that left a residual stand that would not be viable without regeneration (<20 percent canopy cover). Choosing a lower limit of 10 percent canopy cover instead would increase the treatable area by 40 percent with little difference in average hazard improvement, treatment cost, and net revenue. Occasionally, a modeled treatment removed so few trees or so many large trees that assumptions of the harvest cost model were violated and the model could not be applied, forcing us to drop these condition-treatment combinations. As noted earlier, conditions on plots that are too far removed from roads for any treatment to be viable were dropped from the analysis.

Calculating Economic Feasibility

Estimating treatment and transport costs

Plot attributes such as slope, distance to a road, and position on the road network relative to processing facilities (for both merchantable and energy wood) were used to calculate both on-site treatment costs and haul costs. We used a custom, geographic information system-based, travel-time analysis engine parameterized with current truck and driver rental rates ($75/hr) and comprehensive, segment-specific road speed data drawn from several sources to calculate transportation costs. We found the least cost path for moving harvested material to each of up to 259 existing processing sites for merchantable wood and/or biomass energy, producing a haul cost knowledgebase containing over one million entries (round trip travel times >24 hours were filtered out to reduce database size and processing time). On-site treatment costs were estimated for each condition-treatment combination via a version of the Fuel Reduction Cost Simulator (FRCS) that had been updated for this study to reflect circa 2010 costs for various types of logging equipment (Han-Sup Han, personal communication).

Estimating product quantities and values



The "cut lists" generated by FFE-FVS (one list per condition/treatment combination) were linked to the FIA tree tables containing the weight and volume of energy wood derived from tops and limbs from merchantable (trees ≥7 inch dbh) and non-merchantable wood (the entirety of trees <7 inch dbh and non-commercial species of all sizes) and the weight and volume of sawlogs from merchantable trees. Trees less than 5 inches dbh on steep (>40 percent) slopes and less than 3 inches dbh on gentle slope were assumed to be felled, cut in half, and left on site or piled and burned, depending on the treatment.

Delivered product values for merchantable wood were calculated as the product of the harvest quantities and prices by diameter class (for 5-9, 9-16, 16-21, and >21 inch classes) and product species group. The product species groups we used were cedar, Douglas-fir/larch, hardwoods, pine/spruce, true fir/hemlock, and other conifer. Prices were obtained as the three-year average (mid-2007 through mid-2010) of quarterly average delivered prices per thousand board feet in Montana converted to price per cubic foot based on diameter class and product species group calculated from trees in the FIA database. Delivered price of energy wood was assumed to be $36/green ton for all species.

Fire Hazard Criteria and Evaluation

Selecting Evaluation Criteria

The end product of all these analytic steps is a genuinely massive knowledgebase of treatment outcomes, product yields, costs, and revenues that provides unparalleled opportunities for describing "best" alternatives under a wide range of assumptions, objectives, and goals. There are countless ways that treatment effectiveness could be assessed. The best hazard descriptor to focus on will depend on management objectives and, in many cases, more than one hazard descriptor may be relevant. For example, treatments that lead to improvements in the crowning index often produce greater hazard as indicated by torching index, at least as represented in FFE-FVS. Even with a single descriptor, one must decide on the threshold beyond which initial hazard is unacceptable and warrants some kind of treatment, assuming that some kind of treatment can be effective.

The challenge in evaluating treatment effectiveness is to choose a logical basis for evaluating a change in hazard. One can select a particular evaluation criterion—for example, first seeking to achieve success with one descriptor before considering effects on other descriptors, or rely on some weighted combination of change in descriptors. Recognizing this complexity, and that there is no one "right" way to evaluate hazard or treatment effectiveness, we selected thresholds for each of four hazard descriptors (as discussed in Chapter 5): probability of torching >20 percent (ptorch), Torching Index <20 mph (TI), Surface Flame Length >4 ft (SFL), and Mortality Volume Percent >30 percent (MortVolPct). If a descriptor exceeded a hazard threshold, its descriptor score was assigned a 1; if it didn't, a score of 0 was assigned. By adding the four descriptor scores, we obtained a composite hazard score with implicitly equal weights for each descriptor; however, because torching is addressed by two descriptors, that aspect of hazard is implicitly double-weighted. The composite hazard score has a maximum value of 4 (a score of 1 for each descriptor score) and a minimum of 0 (table 11.2).

Table 11.2. Example of hazard score computation for three hypothetical conditions: A, B, and C. Score is incremented by one for each hazard descriptor where the calculated value for a condition exceeds the corresponding threshold.

		Condition		
Descriptor	**Threshold**	**A**	**B**	**C**
Probability of torching (Ptorch)	>20	25	35	15
Torching Index (TI)	<20	18	25	10
Surface flame length (SFL)	>4	5	6	4
Mortality volume (%) (MortVolPct)	>30	25	35	10
Hazard Score		2	4	0

Pre-treatment and post-treatment composite hazard scores were computed for each silvicultural treatment. We calculated a hazard score reduction between pre- and post-treatment (pre-treatment score - post-treatment score = hazard score reduction) for each treatment on each condition. We devised five, rule-based scenarios to explore four alternative perspectives for evaluating treatment effectiveness using the hazard score reduction and selecting a "best" treatment for each forested condition (table 11.3). Two broad types of scenarios were identified: the "Any" scenarios can be thought of as supporting any kind of hazard reduction while the "All" scenarios can be thought of as requiring a post-treatment status in which all hazards have been mitigated (a composite hazard score of 0). Conditions with an initial composite hazard score of 0 were not considered in any scenario because they are already low hazard by definition.

For a treatment to be effective under an "Any" scenario, it had to produce the lowest post-treatment composite hazard score of any treatment. We considered two variations of "Any" scenarios to reflect different assumptions about which treatment would be considered "best" when more than one treatment was capable of achieving the same composite hazard score. Under Any:ptorch, if more than one silvicultural treatment had the same hazard reduction value (for example, two treatments have a post-treatment

Table 11.3. Five scenarios, representing different perspectives and priorities, were developed to evaluate treatment success and select a "best" treatment for all conditions with initial composite hazard scores greater than 0. "NA" indicates not applicable. The "Any" scenarios represent *any* kind of hazard reduction. The "All" requires a post-treatment status where *all* hazards have been mitigated (defined under success defined). In case of ties in the Any:ptorch, if more than one silvicultural treatment had the same post-treatment hazard score, a tie-breaker was selected. The primary tie breaker was dictated on the probability of torching (ptorch). If the observation still resulted in a tie then maximum net revenue was deemed best.

Scenario	**Success defined**	**Optimize (maximize)**	**Primary tie-breaker**	**Secondary tie-breaker**
Any:ptorch	Score Reduction >0	Score reduction	ptorch	net revenue
Any:NetRev	Score Reduction >0	Score reduction	net revenue	NA
All:ptorch	Score = 0	NA	ptorch	net revenue
All:NetRev	Score = 0	NA	net revenue	NA
Any: NR+	Score Reduction >0	Net Revenue	NA	NA

composite hazard score of 2), then the treatment with the lowest post-treatment ptorch is deemed "best." If treatment A leaves ptorch at 10 percent probability while treatment B leaves it at 6 percent probability, treatment B would be selected as "best" if their resultant hazard scores are identical. If, even after this "tie-breaker," a condition has multiple treatments that have the same post-treatment, hazard score, and ptorch, then the treatment with the maximum net revenue is deemed best. If ties remain, then an arbitrary selection is made from among the tied treatments. In essence, we identify which treatments are most effective as a function of fire hazard descriptors. If more than one of these has the same lowest probability of torching, then the one that maximizes net revenue is applied.

Any:NetRev is similar to Any:ptorch except that to break the first tie (two treatments have the same post-treatment composite hazard score), we use maximum net revenue to determine the best treatment without first excluding treatments that do not have the lowest ptorch.

The "All" scenarios define success as moving every hazard descriptor to the "safe" side of its respective threshold so that the post-treatment composite hazard score equals 0 and, like the "Any" scenarios, has two versions that differ only in terms of tie breaking rules: All:NetRev picks a treatment that maximizes net revenue from among those that achieve a 0 hazard score, while All:ptorch excludes treatments that do not have the lowest probability of torching before applying the net revenue criterion.

Note that mean on-site costs vary considerably by sub-region, forest type group, and scenario, but generally range between $1000 and $2000/acre. Though sometimes useful to people familiar with logging cost ranges, cost expressed as dollars per 100 ft^3 of merchantable wood are extremely variable, as there are acres where costs are high but merchantable yield is very low, and other acres where costs are moderate and yields are very high. It does not take many high cost/low yield acres to exert high influence on the mean statistic—in some cases, the median cost per 100 ft^3 is only a fourth of the mean value.

We developed a fifth scenario, dubbed Any:NR+, to identify the "pay their own way" acres where receipts from products (merchantable and energy wood) cover the costs of treatment without requiring subsidy. In this scenario, we only consider treatments that generate positive net revenue, and these are sometimes different than the "best" treatments selected in the other "Any" scenarios.

Findings

What we report here is one possible slice of the knowledgebase based on the conceptualization of hazard discussed in Chapter 5 (based on four hazard descriptors and associated thresholds) and two simple hazard reduction accomplishment criteria: (1) treatment is successful if any reduction in composite hazard score is achieved, or (2) treatment is successful only if composite hazard score is reduced to 0. When more than one treatment will satisfy these effectiveness criteria, heuristics (rules) are applied to choose the best alternative. This section summarizes three kinds of findings from our analysis: (1) scenario-based assessments of treatable area, (2) treatment popularity (or frequency with which treatments are rated "best"), and (3) costs, revenues, and product flows. Results can also be used to compute average potential product quantities, costs, and revenues that could be associated with a fully implemented program of landscape-scale fuel treatment.

Area Treated by Silvicultural Treatments

Nearly 31 million of the 33 million acres analyzed have a hazard score greater than 0. We assumed that to be eligible for fuel treatment, a stand must initially have a canopy cover of at least 20 percent, and over 24 million acres (73 percent) did. On 18.8 million (61 percent) of the 30.8 million acres with a non-0 hazard score, one or more treatment options were effective in reducing the hazard score (though rarely so effective that they reduced it to 0). However, we also assumed that treatments would only be considered if they resulted in residual stands with at least 20 percent canopy cover. This assumption proved highly limiting in that only 5.4 million acres met this criterion (or 18 percent of the acres at risk). The vast majority of acres excluded from treatment by this assumption had a residual canopy cover under 5 percent and were all but indistinguishable from a regeneration harvest. While regeneration harvests are a legitimate management approach in some cases, we focused in this synthesis on mechanical treatments that leave a viable residual stand (as evidenced by a residual canopy cover of at least 20 percent). However, the condition-treatment combinations that remain are a very large (nearly 1000 cases), representative sample of the potential hazard reduction accomplishments, costs, and revenues associated with mechanical fuel treatments on high hazard stands in this landscape. The statistical representativeness of the sample, based as it is on a systematic forest inventory sample, lends great power in making inferences and generalizations from this economic analysis.

Evaluating Treatment Success

Depending on current conditions, the different treatment scenarios and their effectiveness varied by sub-region and forest type. For example, under the Any:ptorch scenario, in the Pacific Northwest Interior and northern California and Klamath, thin-from-below was chosen most frequently as the best option, and restoration ranked second (table 11.4). Restoration was most frequently selected by the model in the northern and central Rocky Mountains (table 11.4). When combined with crown thinning, a total of 72 percent of the area was targeted by these two treatments. The restoration treatment was selected at least as frequently under the All:NetRev scenario; however, thin-from-below was rarely, if ever, rated “best” in any region. This difference is likely driven both by effectiveness

Table 11.4. For the Any:ptorch and All:NetRev scenarios, total acres treated and percent of area for which each treatment best achieves the scenario objectives by sub-region. The overstory treatment types were crown thinning, thin-from-below, and restoration. Two harvesting methods were used to treat the slash: whole tree (WT) and cut-to-length followed by pile and burn (CTL).

		Crown thinning (% of area)			Thin from below (% of area)			Restoration (% of area)		
Sub-region	Acres	Total	WT	CTL	Total	WT	CTL	Total	WT	CTL
					Any:ptorch					
Northern California & Klamath	1,798,299	13	4	8	58	13	45	29	9	19
Pacific Northwest Interior	2,064,415	13	3	10	57	16	41	35	13	17
Northern & Central Rocky Mountains	1,436,080	32	12	20	28	12	16	40	17	24
Utah	112,803	42	30	12	30	12	17	28	16	12
					All:NetRev					
Northern California & Klamath	521,526	4	20	22	10	3	7	49	26	22
Pacific Northwest Interior	417,880	44	16	28	5	4	2	51	36	15
Northern & Central Rocky Mountains	528,457	54	30	24	0	0	0	46	28	18
Utah	6,716	0	0	0	0	0	0	100	0	100

considerations and by the fact that trees harvested under thin-from-below are smaller and generate less revenue than with restoration and crown thinning. In Utah, the crown thinning prescription tended to fit much of the area with about 42 percent of the 113,000 thousand acres being treated under this scenario. Across sub-regions, crown thinning appears to have been more frequently selected for the aspen/birch forest types than for other forest types (table 11.5). The restoration treatment was selected 45 percent of the time for pine and western larch forests; by contrast, crown thinning rated best on only 15 percent of these forests. Within Douglas-fir and True Fir forest types, thin-from-below was the most effective given that it was selected to treat 48 percent of the area, but it also had the fewest acres that produced positive net revenue.

Table 11.5. For the Any:ptorch and the All:NetRev scenarios, total acres treated and percent of area for which each treatment best achieves the scenario objectives by forest type. The overstory treatment types were crown thinning, thin-from-below, and restoration. Two harvesting methods were used to treat the slash: whole tree (WT) and cut-to-length followed by pile and burn (CTL).

		Crown thinning			Thin from below			Restoration		
Sub-region	Acres	Total	WT	CTL	Total	WT	CTL	Total	WT	CTL
					Any:ptorch					
Western redcedar	108,366	0	0	0	61	0	61	39	0	39
Douglas-fir & true fir	2,177,012	25	8	17	48	10	38	27	9	18
Pine and larch	456,263	15	1	14	40	28	12	45	32	13
Aspen/birch	112,400	49	30	19	12	6	6	39	33	6
Other species	2,557,556	14	6	8	43	15	38	34	12	22
					All:NetRev					
Douglas-fir & true fir	781,117	57	30	27	1	0	1	42	26	16
Pine and larch	155,084	44	26	18	12	8	4	44	30	14
Aspen/birch	23,065	33	0	33	0	0	0	67	38	29
Other species	515,313	33	11	22	9	3	6	58	34	24

Table 11.6 summarizes the average change in composite hazard score and five FFE-FVS computed fire hazard metrics for the Any:ptorch scenario for forest type-sub-region combinations with at least 100,000 acres in the study area (i.e., a sample size sufficient to support inferences). The table demonstrates the differences in effectiveness of these treatments among sub-regions and forest type groups and among hazard metrics. Hazard score for this population (which consists of stands where any improvement in hazard can be accomplished by one of the modeled treatments) dropped by 1-2 on average, but the drop was consistently less in the north and central Rocky Mountains sub-region compared to the Pacific Northwest Interior and northern California and Klamath. Signs of changes in hazard metrics were generally, but not always, as expected. For example, torching index dropped, on average, in the pine and larch forests of the north and central Rocky Mountains, indicating an average increase in torching hazard. Ptorch also dropped (suggesting reduced hazard), but by less than any other sub-region-forest type group combination. Average change in surface flame length was sleight, highly variable, and more frequently positive than negative, suggesting that this hazard is comparatively resistant to amelioration via the treatments we modeled. By contrast, MortVolPct was substantially reduced, on average, by 50-60 percentage points in Douglas-fir and true fir, and by 30-40 percentage points in pine and western larch forests. There was considerable variability in mean treatment accomplishment in the Other forest types among sub-regions—perhaps because the composition of Other forests varied so much among sub-regions.

Table 11.6. Average change in composite hazard score, torching index (TI), crowning index (CI), probability of torching (ptorch), surface flame length (SFL), and mortality as a percent of pre-fire live tree volume (MortVolPct), resulting from implementing the best treatments under the Any:ptorch scenario for sub-region/forest type group combinations with at least 100,000 acres in the study area.

Subregion	Acres	Mean hazard score change	Mean TI change (mph)	Mean CI change (mph)	Mean ptorch change	Mean SFL change (ft)	Mean MortVolPct change (%)
			Douglas-fir and true fir				
Northern California & Klamath	368,072	-1.7	89	13	-41	-0.2	-50
PNW Interior	1,028,007	-1.7	59	15	-37	1.0	-57
North and central Rocky Mountains	768,022	-1.2	70	12	-19	0.7	-55
			Pine and larch				
PNW Interior	313,491	-1.8	57	18	-30	0.1	-39
North and central Rocky Mountains	104,468	-1.1	-13	21	-17	1.0	-31
			Other				
Northern California & Klamath	1,378,830	-1.9	195	28	-47	0.0	-55
PNW Interior	697,394	-1.8	98	29	-37	0.3	-61
North and central Rocky Mountains	443,875	-1.2	56	13	-24	-0.2	-26

Costs, Revenues, and Product Flows Associated With Fuel Treatments

We summarize per acre production quantities and values of merchantable wood, energy wood ("dirty chips" suitable for stoking a biomass facility), and associated costs for all four scenarios plus the modified Any hazard reduction scenario (Any:NR+)in which acres are treated only if they "pay their own way" (in other words, net revenue >0). Results are summarized by sub-region (table 11.7) and by forest type group (table 11.8).

Complete data summaries are reported for all sub-regions and forest type groups. However, estimates from sparse samples of forest inventory data are not robust. For example, the statistics for Utah in the All scenarios, representing 7000 acres, is based on a single inventory plot, so a confidence interval can't even be computed. Even the 113,000 acres for Utah in the Any hazard reduction case would be associated with large standard error values (and wide confidence intervals) so the associated estimates should be assumed to be imprecise. In the forest types table, the reliability of estimates for aspen/birch and western redcedar are similarly suspect due to small sample size.

Those cautions aside, these tables provide a wealth of information on quantities and costs of fuel treatment. In general, mean merchantable value in the Net Revenue scenarios (Any:NetRev and All:NetRev) was greater (and/or on-site costs were less) than in the Hazard Reduction scenarios (Any:ptorch and All:ptorch) due to the selection of the treatment with the most net revenue when ties need to be resolved in the Net Revenue scenarios. Wood removals tended to be less in the All scenarios than in the Any scenarios. These scenarios address different populations of acres because the All scenarios require a 0 hazard score post-treatment—a goal that may be impossible to achieve on most acres. As evidenced in Appendix C, summary type 2, the mean pre-treatment hazard score in the All scenarios was less than in the Any scenarios—the frequency with which three or four hazards can be reduced to 0 is likely far smaller than the frequency with which an initial hazard score of risk of 1 or 2 can be reduced to 0.

Table 11.7. Production, economic, hazard, and area statistics, by subregion and scenario. The sub-regions are the Northern California and Klamath (N. California) Pacific Northwest Interior (PNW Interior), northern and central Rocky Mountains (N & C RM), and Utah. Each table entry is a mean value for an attribute for all acres in a sub-region and scenario, or for the entire study area, for a scenario, ordered as follows: merchantable wood produced (ft^3/acre), energy wood produced (green tons/acre), percent of product value generated from energy wood (chips), percent of the total costs of the operation (on site and haul) represented by the cost of hauling chips, on-site costs per 100 ft^3 of merchantable wood recovered, on-site treatment costs ($/acre), value of energy wood ($/acre), value of merchantable wood ($/acre), net revenue ($/acre), and area treated (1000 acres).

Sub-region	Merchantable ft^3/acre	Chips green tons/acre	Chip value as % of all values %	Chip haul costs as % of all costs	On-site cost $/100 ft^3	On-site cost $/acre	Chip value $/acre	Merchantable value $/acre	Net revenue $/acre	Area 1000 acres
					Any:ptorch					
N. California	2,147	30	40	9	289	2,197	1,081	2,379	641	1,798
PNW Interior	1,752	21	23	8	275	1,707	746	3,146	1,746	2,064
N. & C. RM	1,458	9	21	7	477	2,123	307	2,504	330	1,436
Utah	1,336	8	49	31	179	1,161	286	1,137	-506	113
Study Area	1,823	21	29	9	319	1,954	765	2,699	1,015	5,412
					Any:NetRev					
N. California	2,259	32	38	11	257	2,012	1,137	2,947	1,425	1,798
PNW Interior	1,960	23	22	9	197	1,586	841	3,644	2,406	2,064
N. & C. RM	1,476	9	20	8	1,248	1,993	307	2,587	541	1,436
Utah	840	5	46	29	186	798	172	822	-261	113
Study Area	1,943	23	28	10	434	1,803	822	3,119	1,618	5,412
					All:ptorch					
N. California	1,181	17	40	10	582	1,157	597	1,954	1,080	522
PNW Interior	1,009	12	24	8	259	955	430	1,866	1,075	418
N. & C. RM	706	4	23	6	471	2,025	159	1,208	-821	528
Utah	639	5	14	11	473	3,024	182	1,157	-2,101	7
Study Area	986	12	30	8	447	1,355	415	1,705	509	1,475
					All:NetRev					
N. California	1,475	20	36	11	498	1,128	707	2,694	1,898	522
PNW Interior	1,055	12	24	9	247	908	449	2,002	1,260	418
N. & C. RM	687	4	22	7	437	1,914	154	1,175	-745	528
Utah	639	5	14	11	473	3,024	182	1,157	-2,101	7
Study Area	1,109	13	28	9	401	1,297	462	2,026	907	1,475
					Any:NR+					
N. California	2,188	29	25	11	89	1,623	1,061	3,357	2,229	1,003
PNW Interior	1,797	21	20	9	85	1,324	769	3,264	2,254	1,622
N. & C. RM	1,213	7	12	8	93	1,094	242	2,254	1,122	779
Utah	923	5	9	36	77	448	169	2,112	1,369	32
Study Area	2,112	24	20	10	85	1,530	857	3,655	2,456	3,625

Table 11.8. Production, economic, hazard, and area statistics, by forest type group and scenario. Each table entry is a mean value for an attribute for all acres in a forest type group and scenario, or for the entire study area, for a scenario, ordered as follows: merchantable wood produced (ft^3/acre), energy wood produced (green tons/acre), percent of product value generated from energy wood (chips), percent of the total costs of the operation (on-site and haul) represented by the cost of hauling chips, on-site costs per 100 ft^3 of merchantable wood recovered, on-site treatment costs ($/acre), value of energy wood ($/acre), value of merchantable wood ($/acre), net revenue ($/acre), area treated (1000 acres).

Sub-region	Merchantable ft^3/acre	Chips green tons/acre	Chip value as % of all values %	Chip haul costs as % of all costs	On-site cost $/100 ft^3	On-site cost $/acre	Chip value $/acre	Merchantable value $/acre	Net revenue $/acre	Area 1000 acres
					Any:ptorch					
Douglas/true fir	1,757	16	22	6	410	2,217	582	3,050	1,016	2,177
Pine and larch	1,266	13	23	7	146	1,021	468	2,143	1,340	456
Aspen	994	6	63	25	275	857	215	405	-791	112
Cedar	2,010	17	28	6	543	1,574	607	3,655	2,294	108
Other species	2,003	27	34	10	274	1,974	989	2,587	988	2,558
Study Area	1,823	21	29	9	319	1,954	765	2,699	1,015	5,412
					Any:NetRev					
Douglas/true fir	1,903	17	21	7	368	2,078	630	3,403	1,534	2,177
Pine and larch	1,260	13	23	8	136	945	474	2,206	1,486	456
Aspen	701	4	60	24	277	719	159	364	-605	112
Cedar	2,317	21	21	8	288	1,369	749	4,492	3,453	108
Other species	2,135	30	33	12	549	1,802	1,065	3,128	1,738	2,558
Study Area	1,943	23	28	10	434	1,803	822	3,119	1,618	5,412
					All:ptorch					
Douglas/true fir	911	8	26	6	627	1,781	295	1,641	-33	781
Pine and larch	913	9	29	7	271	950	307	1,676	825	155
Aspen	220	2	44	13	320	502	64	306	-256	23
Cedar										0
Other species	1,124	17	33	11	291	1,000	601	1,840	1,086	515
Study Area	986	12	30	8	447	1,355	415	1,705	509	1,475
					All:Net Revenue					
Douglas/true fir	1,032	9	24	7	557	1,750	335	1,910	283	781
Pine and larch	898	8	29	7	258	844	303	1,658	921	155
Aspen	220	2	44	13	320	502	64	306	-256	23
Cedar										0
Other species	1,294	19	32	13	261	922	673	2,333	1,685	515
Study Area	1,109	13	28	9	401	1,297	462	2,026	907	1,475
					Any:Net Revenue +					
Douglas/true fir	2,236	20	16	7	88	1,673	729	4,005	2,570	1,527
Pine and larch	1,548	16	19	8	73	1,107	567	2,651	1,807	352
Aspen	547	4	14	31	92	497	153	942	173	22
Cedar	2,522	21	15	8	90	1,750	769	4,630	3,152	83
Other species	2,130	29	24	12	85	1,501	1,041	3,565	2,498	1,641
Study Area	2,112	24	20	10	85	1,530	857	3,655	2,456	3,625

Chips (energy wood) nearly always generated less than half the overall value, and less than a quarter in the case of acres that "pay their own way" (those included in the Any:NR+ scenario). Haul costs for energy wood as a percent of total operational costs may be a useful indicator for determining the extent to which limited energy wood markets will influence treatment choice. When costs for hauling forest residues are high, it may be economically preferable to burn forest residues at the landing (e.g., in an air curtain destructor) rather than pay for their transport to a distant bioenergy facility. However, this choice forfeits the potential to capture carbon benefits via bioenergy, and as environmental services become an increasingly important component of forest management, this may figure more prominently in such decisions, especially if avoided carbon emissions values increase dramatically (e.g., 5-10 fold) from their very low value today ($2-3/ton) and markets for capturing such values are operating.

Under the All scenarios, mean net revenue is negative in the northern and central Rocky Mountains and under All:ptorch in the Douglas-fir forest type group. While this does not mean that every acre requires subsidy, just as a positive mean net revenue does not assure that no acres would lose money, it suggests that external subsidies (i.e., to supplement the revenue provided from the sale of wood) will often or usually be required to support fuel treatment in those sub-regions or in those forest types.

Every treatment was "best" for some part of the forested landscape, although the relative popularity of treatments, as judged by the rule-based selection, varied by scenario. It appears that the thin-from-below treatments are most frequently chosen for the Any scenarios (under which 18 percent of hazardous acres are treated), while the restoration treatments are most frequent for the All scenarios (under which 5 percent of hazardous acres are treated). Moreover, the harvest method (whole tree or cut-to-length) also presented trade-offs between fire hazard reduction and net revenue. When whole tree harvesting was used, there was higher net revenue because more of the biomass was extracted processed and sold as energy wood. Net revenue increased by an average of $424/acre when ties among treatments were first resolved based on net revenue (i.e., under the Any:NetRev scenario as compared to the Any:ptorch scenario) though much of this net revenue difference was also probably the result of selecting prescriptions that removed more large trees. When cut-to-length was used, slash was left on site (thus sacrificing some revenue and incurring the additional costs of surface fuel treatment). However, by piling and burning the slash, the hazard decreased by removing the fine fuels and decreasing surface flame length. The whole tree harvest method did not contain a pile-and-burn component or have any other kind of post-harvest treatments, so slash that remained was sufficient to increase surface flame length, causing stands to fall short of our hazard reduction criteria in some cases. Similar dynamics can be seen in All:ptorch and All:NetRev, where switching 167,000 acres from crown thinning (CTL) to whole tree harvesting (WT) resulted in an average increase in net revenue from -$391/acre to -$43/acre, along with increases in ptorch (1.6 to 3.2), SFL (2.9 to 3.3 ft), and Mortality (13.8 percent to 15.5 percent of pre-treatment live tree volume). These changes in mean values indicate the trade-offs required to achieve incrementally better hazard reduction (or more feasible treatment), though they are specific to the treatments assumed in this study.

Finding Insights Beyond the Means

One should be cautious about relying excessively on average values, as they do not take into account the considerable variation in fuel treatment outcomes. The effectiveness, costs, revenues, and product flows associated with a fuel treatment can be more fully understood via histograms (frequency distributions) as these depict ranges and dispersion (variability), not just central tendency (such as means). Histograms have the added advantage of clearly depicting when distributions are skewed and the dynamics of treatment effects. For example, comparing untreated and treated plots with respect to a hazard variable such as Mortality Volume Percent in Douglas-fir and true fir stands in the Pacific Northwest Interior—not only does the expected value (mean) drop dramatically (from 82 percent to 25 percent), but a histogram comparison reveals an even more dramatic shift in the modal (most frequent value) tree mortality from 90-100 percent of pre-treatment volume to 0-10 percent after treatment (fig. 11.2).

A compelling reason to invest effort in preparing and understanding histograms is that they provide a clear picture of the range of potential outcomes. For example, fig. 11.3 shows net revenue per acre for conditions in the Pine and western larch forests in the north and central Rocky Mountains under the Any:ptorch scenario. Considering only the mean ($665/acre) and attempting to draw inferences from that, one could reach ill-founded conclusions (for example, we could generally expect to earn this return from treating a few pine and western larch stands in this sub-region). The histogram shows that the mean is not very representative or relevant because there are as many areas below this value as there are above. Also, the range is from -$800/acre to $2100+/acre, reflecting a wide range of potential net revenue outcomes. In addition, a large standard error of $301/acre (nearly half the mean) indicates there is substantial variation in the outcomes. We conclude that the mean is not a very useful representation of this distribution in terms of how many acres can be treated with a particular budget—some will cost a lot and others will pay their own way. The histogram also provides a basis for policy analysis. For example, it is easy to tally the proportion of the forest that could be treated if a subsidy of $200/acre was available: the sum of all bars starting at and to the right of net revenue = -$200.

In this chapter, we report overall findings, often averages, across large areas; however, Appendix C presents sub-region and forest type group-specific histograms of many hazard and economic attributes for the entire study area to help readers obtain locally relevant findings.

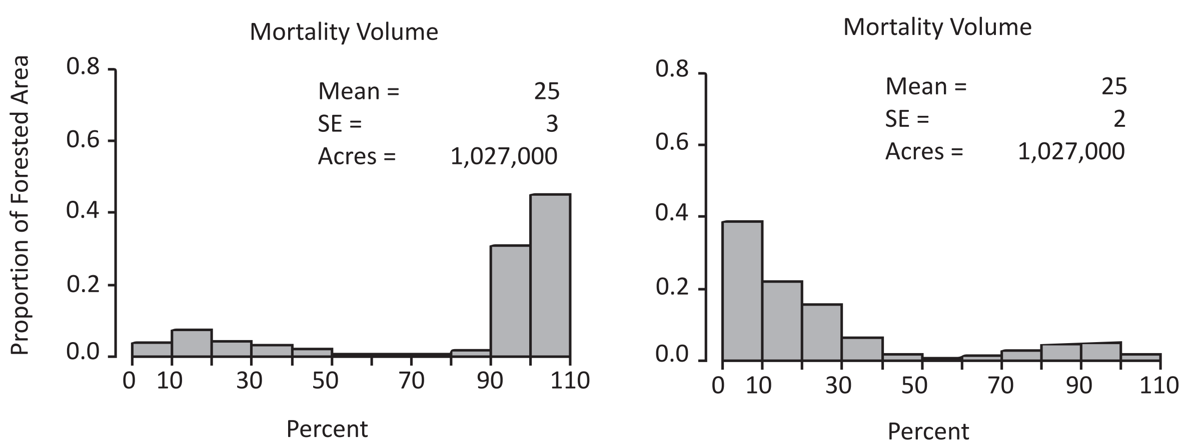


Figure 11.2. Predicted tree mortality shifts dramatically by applying the best treatment under the assumptions of the Any:ptorch scenario in the Pacific Northwest Interior sub-region's Douglas-fir and True Fir forests. Pre-treatment, most stands experienced 90 to 100 percent mortality, and post-treatment, the distribution changed so that 10 and 20 percent mortality rates were far more common.

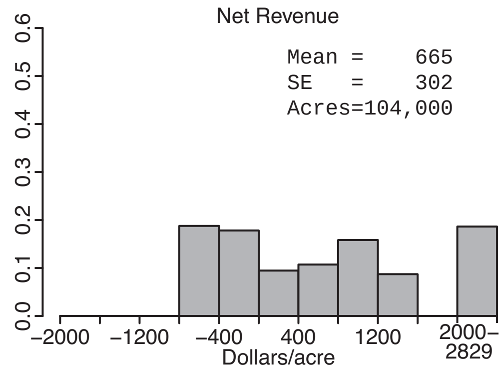


Figure 11.3. Distribution of net revenue per acre for conditions in the Douglas-fir and True Fir forest type group in the northern and central Rocky Mountains under Scenario 1. Y-axis values are the proportion of forested area at each value range of net revenue.

Discussion

The evaluations of treatments and characterization of treatable area, levels of products produced, and likely costs of a fuel treatment program that follow are dependent on whether the hazard criteria we devised (for example, attributes and their thresholds) are valid and whether the hazard descriptors are equally important (given how we combined them into a composite hazard score or required that all hazards be decreased in order to label a treatment "successful" under some scenarios). Moreover, there is no guarantee that in the "Any" scenarios, we do not end up with an improvement in two hazard descriptors but a worsening of another. For example, Mortality might decrease to less than 20 percent and SFL might decrease to less than 4 ft, but ptorch might increase to more than 20 percent. It is also possible for some hazard descriptors to trend toward greater hazard following a "successful" treatment, even if they do not exceed our somewhat subjectively chosen thresholds. However, the intent of this analysis was to evaluate fuel treatment economics, so some characterization of treatment effectiveness is unavoidable if we are to produce meaningful conclusions about treatment feasibility for treatments and places that actually make sense.

This analysis reveals that, at least under our definitions of hazards and treatment effectiveness, most dry mixed conifer forests currently have high fire hazard, and only a fraction of those forests can be effectively treated (at least by the fuel treatments that we modeled that were intended to represent the style of thinning treatments typically undertaken in the dry mixed conifer region). While this might be viewed as discouraging in that prospects for effective treatment are limited to a relatively small subset of the forest, it does make the fuels management problem more workable in that it gives license to tackle a more limited area of forest. It also suggests that on many acres, choices are limited: hazard reduction is not an achievable goal, or a major reset in expectations is required—almost twice as much area could be effectively treated if the constraint that residual stands must support a canopy cover of 20 percent is removed. Conversely, initial exploration using BioSum with other kinds of thinning treatments focused exclusively on fire hazards that leave more overstory and perhaps reduce effective surface wind speeds as computed in FFE-FVS indicates that treatable area could as much as double given the same assumptions and scenarios but different treatment options, though the costs and feasibility would be different.

When material removed by a fuel treatment is utilized for wood products and bioenergy, revenues contribute a great deal to off-setting treatment costs and, on most acres, can more than offset the costs of treatment activities and transportion of harvested material, though this varies by sub-region and effectiveness scenario. For example, in Utah, mean net revenues were negative under every scenario except (by definition) Any:NR+ given that acres are treated only if net revenue is ≥0, and were negative in the northern and central Rocky Mountains under the All:ptorch and All:NetRev scenarios. Aspen had negative mean net revenues because of the low commercial values of harvested material (most is utilized for energy wood in our scenarios). In most scenarios, net revenue was greater for pine and western larch than for Douglas-fir and true fir, and scenario assumptions are extremely influential. For example, comparing All:ptorch with All:NetRev, both of which require a residual composite hazard score of 0, we see that when ties among treatments that achieve this goal are resolved by choosing the treatment with lowest residual stand ptorch value, the result is a mean net revenue per acre for pine and fir of $825 and -$33, respectively. When ties are instead resolved by choosing the treatment with the greatest net revenue, mean net revenues are $921/acre and $283/acre, respectively. This highlights the importance of hazard and effectiveness definitions, as well as how to determine the "best" treatment when there is more than one way to achieve a given hazard score.

The Any scenarios, which attempt the best that can be done to reduce hazard score, even when a 0 hazard score post-treatment is not achievable, can be implemented on more than three times as many acres as the All scenarios, and on average, achieve a big drop (from 2.8 to 1.1) in hazard score. The All scenarios achieve about the same numerical reduction in hazard score (by 1.7) on the far smaller selection of acres they treat and leave these acres with a 0 hazard score, but this would also be achieved on these same acres under the Any scenarios because they also pick the treatment that maximizes hazard score reduction on these acres. Net revenue under the Any scenarios is higher than for the All scenarios because the Any scenarios add acres of fuel treatment that generate more revenue relative to costs, even if treatment effectiveness on those acres is less impressive than on the acres that meet the All requirements.

The huge gap in both treatment area and net revenue between the "Any" and "All" scenarios highlights the importance of first focusing on the treatment goals to reduce fire hazard, regardless of economic implications. Selecting acres for treatment that are not genuinely hazardous, or that fall short in terms of what can be demonstrated analytically for the sake of economic viability of a fuel treatment program, presents risks to gaining and maintaining public trust in fuels management. Models such as BioSum and FFE-FVS provide the decision support that can be used to demonstrate treatment accomplishment (effectiveness and economics) objectively and provide a science basis for choosing a given treatment. For example, the models could be used to show that other, more financially rewarding treatments were not selected because they were predicted to be ineffective by the model. And in most cases, they can show that a treatment that puts all trees over a certain size (say 10 or 14 inches dbh) off-limits to harvest is ineffective under almost any effectiveness criterion.

Best Places to Add Processing Capacity

One interesting finding is that, except in Utah where bioenergy facilities are largely absent and the benefits of adding some bioenergy capacity are fairly compelling, a lack of transportation infrastructure and energy wood markets does not appear to be the most limiting factor in fuel treatment feasibility. Most of the wood produced by the treatments we modeled is of merchantable size, and by far, most of the revenue that could be used to support fuel treatment activities comes from sales of merchantable wood. On average, the mass of merchantable wood flowing from these fuel treatments in the pine and fir type classes under these scenarios is nearly three times the mass of energy wood, yet energy wood contributes to the bottom line when there are nearby markets. The great majority of the treatment costs are on-site costs, and prices for delivered wood are apparently high enough to support treatment activity even when material must be delivered relatively long distances to be processed. A key determinant of financial feasibility, then, is removal of at least some merchantable trees, and this is likely a more important consideration than is the cost for transporting the low-valued energy wood derived from small trees. This requires a willingness by managers to design treatments that include removing merchantable trees and a granting of social license to do so by parties with a stake who are interested in the implementation details of fuel management.

Note that this analysis has some aspects in common with earlier work that led to Johnson and others (2007a, 2007b) and more recent work testing the principles of a fire-safe forest (Johnson and others 2011). Like the analysis presented here, Johnson and others relied on FFE-FVS to apply alternative prescriptions for canopy and surface fuels to inventory plots and relies on FVS default assignments of surface fuel models. Unlike this BioSum analysis, which modeled the entire dry mixed conifer forest via thousands of statistically representative inventory plots, the analysis that led to Johnson and others (2007a) modeled just a handful of analyst-selected stands per region, matched up data from local weather stations to get the best representation of severe weather with which to parameterize the FFE-FVS model for those stands, and projected stand attributes forward for five decades with and without treatment, producing pages of detailed model reports for each stand (Johnson and others 2007a). The analysis that tested the principles of a fire-safe forest (Johnson and others 2011) extracted from the FSVEG corporate database tens of thousands of National Forest inventory plots (not based on a statistical sample) and selected only those with greater than 700 trees per acre to model using four levels of residual trees per acre and several surface fuel treatments, limiting the capacity to make inferences about the whole forest. By contrast, this BioSum analysis was designed to produce summary information that reflected effectiveness and economics of treatment opportunities over the entire forest, and to explore the kinds of treatment options that are actually being practiced, which are typically less straightforward than a residual trees per acre target.

A few caveats must be noted. This analysis depends for its characterization of hazard and effectiveness on both a set of logically structured, but inherently subjective assumptions (about hazard attributes and thresholds) and the accuracy of the FFE-FVS model. We relied on each FFE variant's default characterization of surface fuels and severe weather. More accurate representations of these parameters may be possible using local data. We also assume currently available technology, equipment, and practices for conducting fuel treatments. It is always possible that lower-cost techniques for mechanical removal will be developed that could reduce fuel treatment costs. It is also possible, and desirable, that product values for both merchantable and energy wood will increase above the values used for this analysis. As the carbon benefits of wood use (instead of steel, concrete, and plastic) become more widely appreciated and translate to building codes, incentives, and other policies that favor wood use, product prices could rise. Along the same lines, renewable portfolio standards that give credit for bioenergy may already be elevating the price for energy wood above where it would otherwise be; any movement toward carbon taxes, or cap and trade systems—even at the state level as has been occurring in California— could further elevate the price of energy wood, pushing additional acres into the range of feasibility.

Conclusion

In addition to exploring other kinds of treatments in the dry mixed conifer types using the BioSum system, we see potential to develop models from this dataset that can be used to predict costs and effectiveness from key stand attributes, for example, descriptors of stand structure, slope, distance from the nearest road, and distance from processing facilities. This dataset is already being analyzed to assess carbon implications of fuel treatments, accounting for full life cycle analysis of treatment generated products and energy wood and the model-based mortality predictions with and without fuel treatment.

To be truly effective in mitigating fuel hazard, it is important to pursue all options that promote self-funding fuel treatments. Given the current and likely future Federal budget climate, it is hard to imagine successful implementation of anything but treatments that pay their own way for the foreseeable future. The future of active forest management on public lands may well depend on reconciling ourselves as foresters and natural resource professionals to that hard reality.

Chapter 12

Fuel Dynamics and Treatment Longevity

Chapter Rationale

The dry mixed conifer forests are quite productive compared to the dry ponderosa pine forests in the Southwest. Therefore, treatment longevity will in some places be relatively short. An important question arose in our interviews: How often should I conduct fuel treatment maintenance? In this chapter, we address questions such as:

- What is the current information on fuel treatment longevity?
- How do treatments affect fire behavior as forest stands grow and develop after a treatment is implemented?
- Are there options during initial implementation to increase the longevity of a fuel treatment?

Introduction

Forest fuel treatments are commonly evaluated by managers for their immediate effects on potential fire behavior, but since forests are dynamic systems, post-treatment conditions will change over time and treatment alternatives will vary in the duration of their effectiveness, or treatment longevity. An understanding of forest fuel treatment longevity and the processes contributing to it is central to a complete evaluation of the effectiveness of treatment alternatives.

In this section, we provide fuel managers with a summary of the information on treatment longevity. We review current knowledge and describe the elements of forest dynamics that collectively determine fuel treatment longevity. Longevity is a general concept, but the processes contributing to it are specific and many are founded on well-developed relationships that underpin silvicultural practices. We summarize them and propose a conceptual model that links those often dissimilar processes. We also evaluate the potential and limitations of available decision tools that aid fuel managers in comparing the longevity of treatment alternatives, and identify opportunities where improvements to the understanding of treatment longevity can be made.

Longevity In Fuel Treatment Planning

Longevity is an important, oft-overlooked consideration in fuel treatment planning. As Reinhardt and others (2008) noted, "A common misconception is that fuel treatments are durable and will last for a long time. In reality, fuel treatments have a somewhat limited lifespan." Fuel loads, as well as their availability, change tremendously following treatment. This is true in both the short- and long-term. Although it is important, fuel treatment longevity is often overlooked or oversimplified. This is even apparent in modeling: when projecting fuel conditions, model users often maintain static fuel values (Varner and Keyes 2009).

Longevity is an important consideration for different fuels management objectives. Fuel is not inventoried regularly, so understanding longevity is important for anticipating changes that have occurred to the fuel load of a site and its potential fire behavior since the previous fuel treatment. The degree to which longevity is accurately estimated will affect suppression opportunities and firefighter safety, the determination of whether points or areas can be successfully protected, and whether areas of special concern possess the resilience to survive a wildfire.

In prescribing fuel treatments, managers can select alternatives that are not only effective today but also possess attributes that enable their effectiveness to persist into the future. Incorporating longevity into prescriptions reduces the annualized costs of the treatment and enables more area or new areas to be treated rather than re-treating the same areas.Shortcomings in treatment longevity can be mitigated only by frequent re-treatment. Reinhardt and others (2008) concluded, "Fuel treatment benefits are transient...we must think of fuel treatment regimes rather than single fuel treatment projects."Approaching fuels planning in this way encourages managers to consider elements of longevity and the effects of treatment alternatives on longevity. Treatments with low longevity will require greater frequency in re-treatment and shorter periods between those re-treatments.

Managers have noted a concern that current fuel treatments can (if not adequately planned) create an unmanageable future workload for fuel maintenance that cannot be met. Initial fuel treatments can generate merchantable products that offset treatment costs (in the case of treatments that involve commercial thinning). But often those merchantable elements are not available during subsequent entries, which will necessarily focus on new growth and ladder fuels. Adopting a regime-based approach to fuels management that considers treatment longevity can help alleviate this concern.

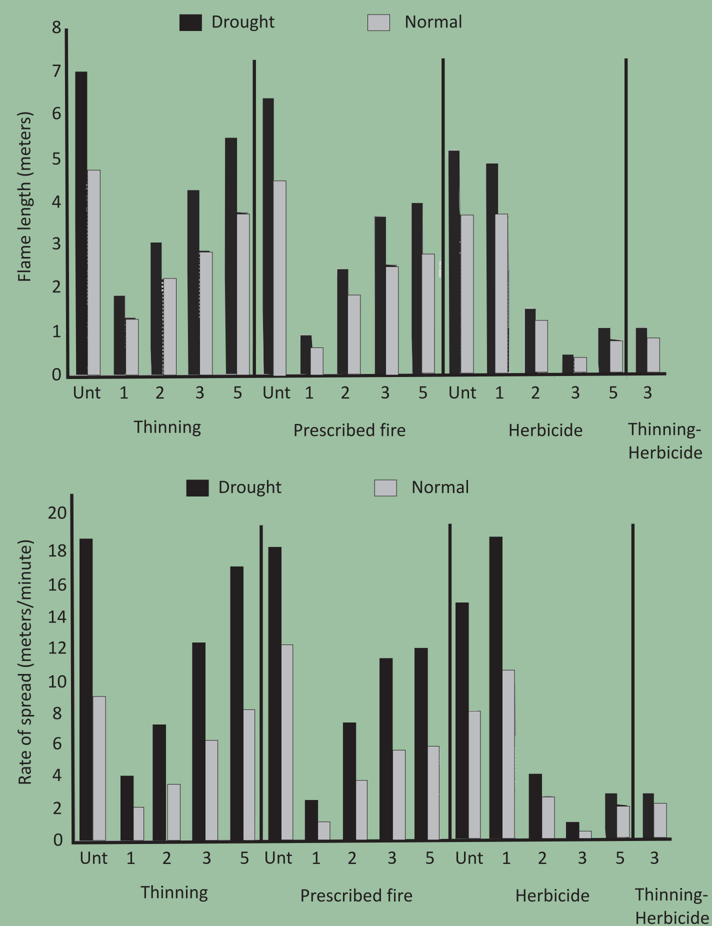
Studies of Treatment Longevity

Empirical data on treatment longevity are scarce. Few studies have quantified changes in fuels following treatment. The existing post-treatment analyses are limited to just a few years after treatment. For example, Martinson and Omi (2003) evaluated fuel treatment effectiveness in stands that were subjected to wildfire less than five years following treatment. As a result, the majority of fuel modeling studies have ignored treatment longevity altogether and focus instead on the immediate effect of treatment alternatives on fuels and potential fire behavior (for example, Stephens 1998).

In the West, longevity studies are mainly limited to locations where continuous inventory of fuel loads in prescribed fire monitoring programs has allowed for the analysis of post-burn fuel load recovery. At Yosemite National Park, for example, fuel loads recovered to 55 percent of pre-treatment levels within six years (van Wagtendonk and Sydoriak 1987). Within a decade of prescribed fire treatments at Sequoia and Kings Canyon National Parks, ponderosa pine forest fuel loads recovered to 84 percent of pre-treatment levels, and white fir/mixed-conifer forests recovered to 83 percent of pre-treatment levels (Keifer and others 2006). In that study, ponderosa pine forest fuel loads (fine and sound woody fuels) at Yosemite National Park exceeded pre-treatment levels within 31 years.

Knowledge of fuel accumulation and decomposition rates can provide insight into dead surface fuel loads, which can help managers anticipate treatment longevity (Fernandes and Botelho 2003). At higher elevations, snow pack can also reduce the depth of treatment-generated slash. In the study by Keifer and others (2006), white fir and giant sequoia/mixed-conifer forests left untreated for approximately 40 to 90 years exhibited slow rates of surface fuel accumulation, leading the authors to speculate that decay and accumulation rates had achieved a steady state. Nevertheless, for the most part, A severe wildfire season in Florida in 1998 inspired one of the few direct comparisons of the longevity of common fuel treatments on fuel loads and potential fire behavior. Researchers evaluated different fuel treatments (prescribed fire, thinning, and herbicides) applied to vegetation in pine flatwood forests, measuring fuel loads in stands from one to five years following each treatment (Brose and Wade 2002). From those data, they created custom fuel models, simulated potential fire behavior using BEHAVE, and compared the results among treatments and a no-treatment alternative.

Thinning and prescribed fire treatments were far more effective than herbicide treatments on immediate post-treatment surface fire flame lengths and spread rates. But that effectiveness steadily waned in the following years as the understory vegetation rebounded in growth, such that within five years, simulated flame lengths approached the no-treatment levels. In contrast, herbicide treatments had no effect on immediate post-treatment flame lengths and actually increased spread rates. But thereafter, as the dead surface fuels decayed, fire behavior dropped sharply and remained low through year five. The forest contexts and fuel treatments will differ in other places, and the five-year period is probably insufficient for adequately comparing the longevity of fuel treatment alternatives. Nonetheless, the study demonstrates the importance of evaluating fuel treatments on the basis of longevity and shows how that approach can reveal important differences among treatment alternatives that can only become apparent over time.



Simulated wildfire flame lengths (top) and spread rates (bottom) for fuel treatment alternatives from untreated ("Unt") through year five for drought and normal weather scenarios (redrafted from Brose and Wade 2002). The treatments differed dramatically in both their immediate post-treatment effects and in trends over time. Thinning and prescribed fire treatments had the greatest but shortest-lived effect on fire behavior; herbicide treatments showed a slower response but greater longevity.

fuel accumulation and decomposition models are still in development, and with few exceptions, such as Keane's (2008) study of northern Rocky Mountain forests, those rates are poorly understood for many ecosystems. Among Keane's findings were the following: (1) litterfall rates are highest on the most productive sites with highest stand densities, (2) litterfall rates differ by cover types and site qualities but the distribution by woody fuel type is about the same, and (3) decomposition rates are greatest on the most productive sites.

Work by Vaillant and others (in preparation) should shed light on treatment longevity in California forests. A previous study that evaluated the effects of mechanical treatments and prescribed fire on 14 California National Forests (Vaillant and others 2009) revealed widely different effects on post-treatment fuel structures between these two approaches. That study's permanent plot network, initiated in 2000 immediately prior to operational fuel treatments, now serves as a key tool for monitoring changes over time to fuel loads and potential fire behaviors associated with different treatment types.

Empirical knowledge regarding treatment longevity still lags, but fuel treatment studies and reviews have increasingly acknowledged the subject of longevity and longevity-related responses. For example, in the southern Rocky Mountains and on the Colorado plateau, mastication (mulching) treatments have shown to be suitable for replacing or complementing traditional thinning treatments. In their examination of near term treatment effects, Battaglia and others (2010) noted and discussed the potential longevity-related effects of mastication treatments, including potentially different fuel moisture dynamics, fuel decomposition rates, vegetation recruitment patterns (including invasive species), nitrogen cycles and site productivity, and rates of tree seedling establishment and growth. Each of these elements operates as a driver of longevity, but the cumulative effect is unclear. For example, ladder fuel development might be accelerated by enhancement of site productivity as the mulch layers decompose, or the mulch layer might serve as a physical obstruction that delays tree seedling recruitment and enhances longevity. The authors concluded that the number of factors and their interactions requires the study of long-term responses in order to quantify the longevity of this treatment. We are aware of some cases in which managers have opportunistically performed their own local, informal comparisons of fuel treatment alternatives (for example, mastication versus hand thinning and piling), but are unaware of any attempt by researchers or others to formally document the extent of such case studies and their collective inferential value.

Longevity is a complicated and dynamic phenomenon, but the main elements can be distinguished and treated separately in three distinct categories, each of which influences treatment longevity: (1) fuel decay, (2) fuel growth, and (3) fuel recruitment. The first focuses on dead surface fuels; the second and third focus on live surface and canopy fuels. Interrelated disturbances constitute a fourth category that can strongly influence longevity. Examples include fuel treatment interactions with bark beetle damage. However, for simplification in this review, we set those extraneous agents of disturbance aside and focus on the direct effects of fuel treatments on subsequent changes to fuels.

Dead Surface Fuels and Longevity

Decomposition rates of dead surface fuels are primarily affected by site quality and climate. Whereas higher site qualities promote ladder and crown fuel growth, they also promote a more rapid degradation of dead activity fuels generated from the fuel treatment. Decomposition rates are most strongly determined by those same attributes that drive site quality: temperature and precipitation regimes. Decomposition is facilitated by contact with the ground and other particles, but compaction can slow decomposition. Consequently, higher-quality sites see more rapid deterioration of dead surface fuels that are generated by treatment activity. However, the type of fuel treatment can determine slash quantity and height, or bulk density. The amount of residual overstory and its spatial arrangement can have strong effects on surface fuel loads and availability (Carlton and Pickford 1982).

In many cases, maintaining soil productivity or wildlife habitat often requires retaining a certain proportion of woody debris after harvest. The retention of activity fuels to serve wildlife habitat requirements may not necessarily pose a fire hazard (Reynolds and others 1992). If a fuel hazard is identified, surrounding it with less hazardous fuels can often isolate it. It is widely assumed that fuel treatments involving commercial thinning will inflate surface fuel loads via the pulse of slash created during the cutting process. Those concerns can usually be addressed by matching harvest techniques to the silvicultural prescription in combinations that meet slash and woody debris targets. Selection of harvesting equipment and practices are based in part on site and stand conditions and on the silvicultural prescription. Integrating these aspects early in the planning process can result in the selection of systems that avoid fuel jackpots (heavy fuel concentrations) or that reduce activity fuels via underburning or jackpot burning. The development of biomass markets in some locations may yield an additional instrument for managing activity fuel accumulations. Alternatively, contract specifications can serve to relegate the excessive biomass in closer contact with the ground to enhance decomposition or require post-harvest activities to redistribute heavy pockets of fuel.

Forest Stand Dynamics as Forest Fuel Dynamics

The elements that drive vegetation responses to fuel treatments are reasonably well understood. Lacking adequate model support, an understanding of principles of vegetation dynamics that are affected by treatments is vital. The models may be limited, but forest fuels consist simply of dead and live vegetation that grow, decay, and regenerate and do so in ways that are reasonably well understood from past studies in silvics, silviculture, and ecology. If these dynamics cannot be quantified, they can at least be understood in ways that let managers better simulate treatment effects and better choose between treatment alternatives on the basis of longevity.

Post-treatment conditions differ in their capacity for vegetative change. Vegetation that remains following treatment is positioned for accelerated growth. Like all forms of natural or human disturbance, fuel treatments create vacancies in available growing space that will be exploited by the growth of the remaining vegetation. Among that vegetation, the patterns of development following a disturbance (such as a fuel treatment) will be similar across a range of sites, but the rates of change will differ.

Crown Fuels Growth

Familiarity with stand development patterns allows for better understanding of crown fuel dynamics that affect potential fire behavior and the effect of thinning treatments on those patterns. Forest stand density in particular is a strong determinant of the morphological development of trees, including crown fuel loads and crown base heights. Spacing strongly affects the process of crown recession, which occurs as the lower branches are shed in response to declining light conditions. In general, early successional species readily self-prune, but late successional species tend to retain branches even in closed conditions. Figure 12.1 illustrates the typical relationship of inter-tree spacing to crown development that is observed in even-aged pure stands or cohorts. Collectively, the crown recession patterns among individual trees determine the lifting of canopy base height in such closed-canopy stands.

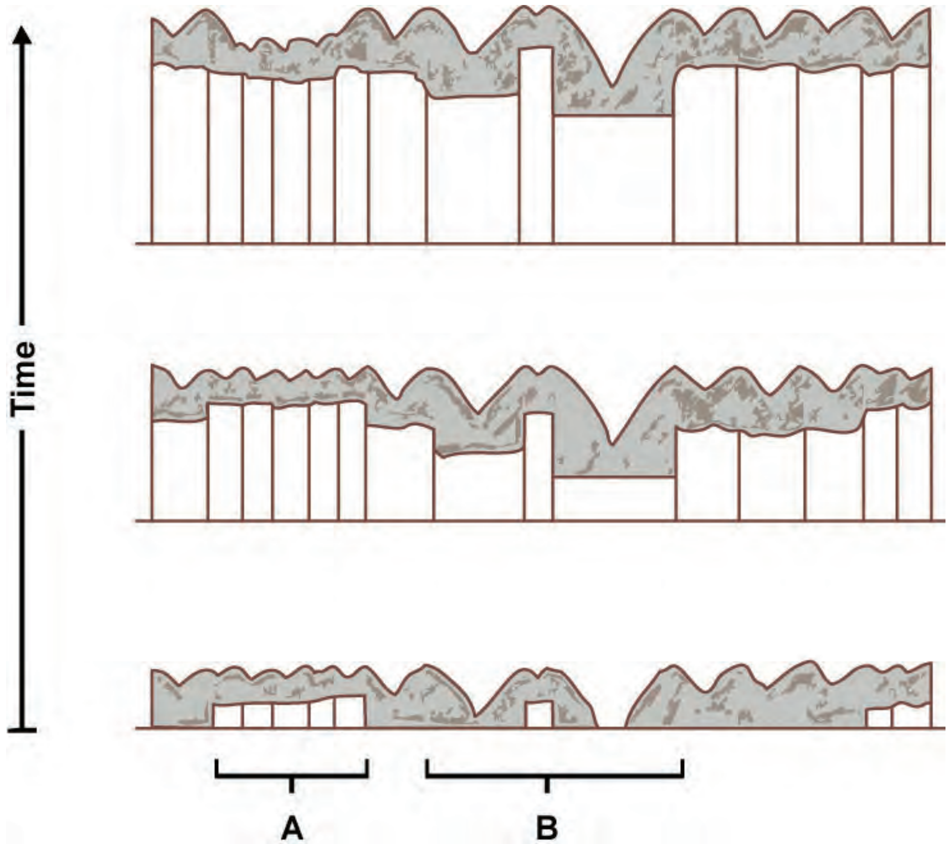


Figure 12.1. Generalized relationship of spacing to crown and canopy development in even-aged pure stands or cohorts, here through three phases following establishment (based on figure from Oliver and Larson 1996). The figure demonstrates how inter-tree spacings within a stand affect crown development of individual trees over time. For fuels managers, the concept is directly transferable to understanding thinning effects on crown fuel dynamics, and canopy base height in particular. Of special note here is that crown recession occurs earlier and more rapidly for trees at dense spacings (A), and occurs later and more slowly for trees at wider spacings (B). At first stage (bottom), crown recession has commenced among those trees at close spacings. By the third stage (top), the initial variability in spacing has been manifested in an uneven canopy base height.

Although thinning reduces near-term crown fire behavior by reducing canopy bulk densities, it interrupts the natural recession of crown bases. There are many good reasons for thinning and maintaining low stand densities in addition to fuel management objectives; however, the effect of thinning intensity on temporal patterns of canopy base height development (and therefore crown fire initiation potential and torching index) is important to recognize and account for in prescription development, if longevity is a consideration.

Figure 12.2 provides an example of this situation. An even-aged ponderosa pine stand in central Oregon was subjected to a fuel reduction-based crown thinning to reduce canopy bulk density. Previous stand development had served to steadily lift the canopy base height to its current height at the time of treatment. The thinning successfully reduced canopy bulk density but it also stalled crown recession; during the

Figure 12.2. Thinning intensity in canopy fuel treatment often involves a trade-off between immediate treatment impact and treatment longevity. In this example from central Oregon, heavy thinning in a ponderosa pine /mixed-conifer stand successfully reduced canopy bulk density. However, it stalled crown recession and promoted the development of ladder fuels, thereby reducing the capacity of the stand to sustain a reduced torching potential over time.

15 years following treatment, the canopy base height remained constant while ladder fuels became established and grew rapidly. A lighter thinning would have resulted in a lesser reduction in canopy bulk density but could have enabled crown recession to continue while also suppressing the recruitment of ladder fuels, thereby sustaining a lower torching potential in the stand over a longer period.

Trees grown at low densities have lower canopy base heights (if always grown in that condition) than if they are grown in dense stands and then thinned, in which case they often have a higher crown base height. This is particularly true of shade-intolerant early successional species such as ponderosa pine, and less so of shade-tolerant late successional species in which lower branches are retained at similar density and understory light levels. A great deal of crown modeling work has been performed by researchers beyond the fire science community. Such crown research offers much potential to inform further development of canopy fuel models. However, information about the time lag size classes (1-hour, 10-hour, etc.) typically required for application in fire behavior models is usually not distinguished in research performed in other fields (Affleck and others 2012).

Fuel treatment effects on crown fuel characteristics have been simulated but not observed. In one study of temporal changes to crown fuel characteristics, Scott and Reinhardt (2007) utilized FFE-FVS to simulate the effect of various treatments on crown fuels. Yet it appears that no long-term study of actual fuel treatment effects on observed crown fuel characteristics has been conducted to date. It seems that the prevalence of several silvicultural trials—thinning studies and levels-of-growing-stock (LOGS) studies—could provide information on post-treatment crown dynamics and the accuracy with which the crowns are characterized by the present generation of fuels models (Affleck and others 2012).

Live Surface and Ladder Fuels Growth

Latent ladder fuels affect longevity and are affected by fuel treatments. In many forests, latent ladder fuels exist in the form of advance regeneration—seedlings and saplings occurring in the understory that are capable of accelerated growth upon disturbance to (or cutting of) the overstory. In contrast to dry ponderosa pine forests, dry mixed conifer forests often include species with high or moderate shade tolerance, and advance regeneration of those species beneath a ponderosa pine dominated canopy is common. The rate of accelerated growth upon treatment is proportional to site quality and thinning intensity.

Ladder fuel growth is governed by the number and sizes of overstory trees. The relation of overstory trees to understory growth has been a subject of concern in two-age and uneven-aged silvicultural systems. Some studies have regarded overstory trees as inhibitors of seedling growth, but they can help fuel managers identify cutting levels that meet fuels management goals yet suppress seedling (ladder fuel) growth. One concise illustration of the relationship in dry mixed conifer forests was provided by McDonald (1976) who studied regeneration growth beneath ponderosa pine seed tree harvests at the Challenge Experimental Forest in northern California (fig. 12.3). Some of the cutting levels in that study exceed what fuels managers would consider reasonable fuel treatments, but the study demonstrates how ladder fuel development is directly related to the distance from overstory trees and negatively related to the amount of overstory density retained.

Another illustration of this phenomenon is provided by a LOGS thinning installation at Pringle Falls Experimental Forest in central Oregon (fig. 12.4). Seedling regeneration was not a focus of the study, nor did it occur at any thinning levels, except at the two heaviest thinnings that retained overstories of 60 ft^2/acre and 30 ft^2/acre basal area.

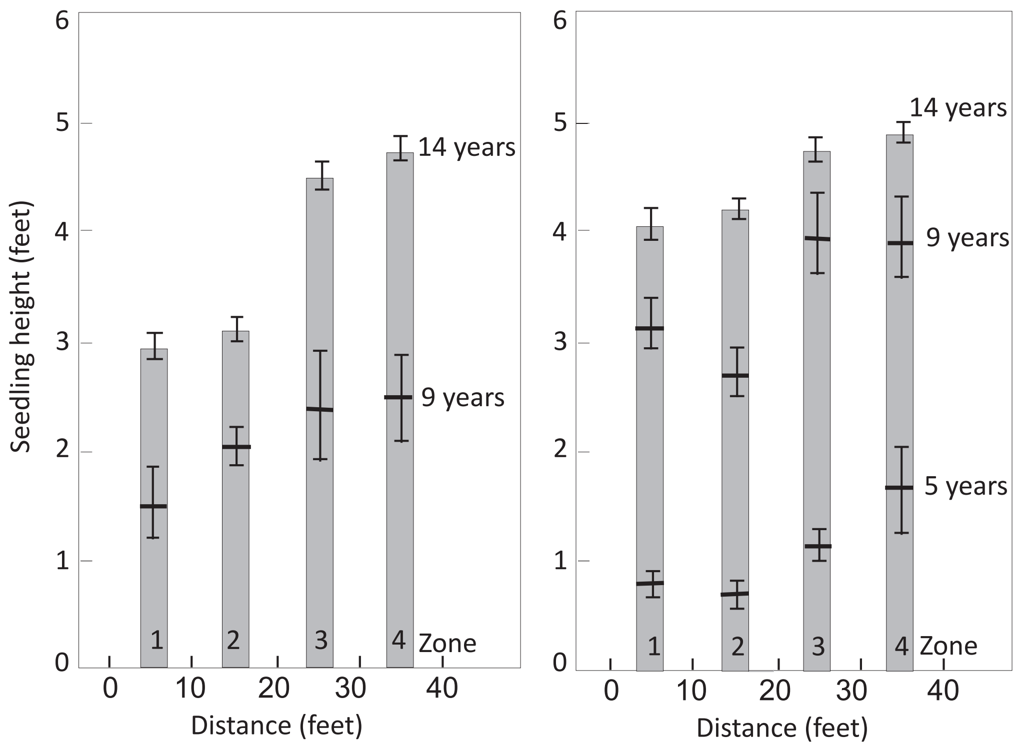


Figure 12.3—Figures from McDonald's (1976) study of the effect of overstory tree distance (0 to 40 ft) to regeneration (ladder fuel) height development at 5, 9, and 14 years following treatment. At left, the cutting treatment retained 12 trees per acre; at right, the treatment retained 8 trees per acre. Most fuel treatments will retain more overstory trees, but this example demonstrates how ladder fuel development is directly related to the distance from overstory trees and negatively related to the amount of overstory density retained.

At the 60 ft^2/acre cutting level, seedling recruitment was present but was scant and its height growth was minimal. At the 30 ft^2/acre cutting level, regeneration was prolific and growing rapidly into the subcanopy. As a fuel treatment, the latter prescription would require maintenance relatively soon, whereas re-treatment in the former prescription will remain unnecessary for many years.

In addition to the number of trees left following treatment, the sizes of those trees is an important influence on ladder fuel growth. Based on data from a ponderosa pine variable-retention silvicultural study in central Oregon, the model in fig. 12.5 provides a quantitative illustration of how the two work together to suppress understory height growth. In this example, the lines signify the reduction in a site's capacity for ladder fuel height growth (average annual height growth) occurring beneath overstories that vary in the number and sizes of canopy trees retained following treatment. Plotting the number of retained overstory trees (X-axis) and their average size (Y-axis), the user identifies the diagonal line closest to the x-y pair; its associated number indicates the effective reduction in ladder fuel height growth (meters) over a 100-year period, versus seedlings growing at the same site in an open condition. The scope of inference is limited to central Oregon, from which that modeling effort drew stand and regeneration data, but it concisely demonstrates how retaining more and larger trees serves to suppress ladder fuel development.

Figure 12.4. Untreated ladder fuels development beneath two thinning levels at a LOGS study installation, Pringle Falls Experimental Forest, central Oregon. Top, overstory thinned to 30 ft^2/ac basal area; Bottom, overstory thinned to 60 ft^2/acre basal area.

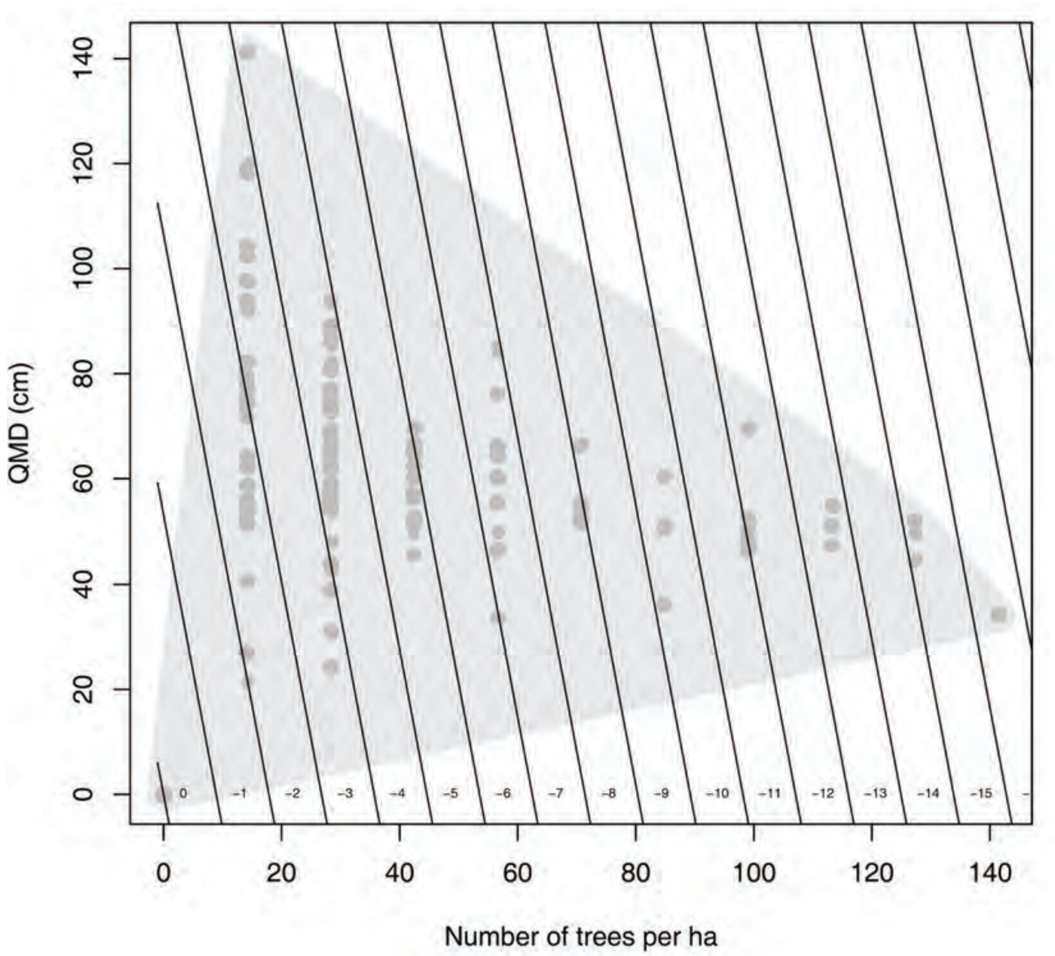


Figure 12.5. Fuels treatments that resemble thinnings or shelterwood harvests will vary in their suppression of ladder fuel development over time, depending on the number and sizes of trees retained following treatment. Data from a variable-retention study in central Oregon dry mixed conifer forests dominated by ponderosa pine are used here to model that relationship. The overstory tree sizes (QMD; or quadratic mean diameter, Y-axis) and numbers (Trees per hectare; X-axis) together determine the suppression of regeneration height growth rates. The diagonal lines denote the projected reduction in ladder fuel height growth (meters) over 100 years, relative to open-grown trees at the same site.

Ladder Fuels Recruitment

Recruitment of new ladder fuels quickly reduces longevity. The recruitment of ladder fuels is highly complex and dependent upon the co-occurrence of multiple factors (regeneration dynamics), including: seed production, seed dispersal, seed predation, germination, establishment, and early survival. Although these have been addressed in separate or several stages at a time, comprehensive models are just now being developed and are highly complicated. Therefore, an understanding of the general principles of tree (ladder fuel) recruitment is vital for fuels managers to adequately anticipate the effect of fuel treatments on this aspect of longevity.

Studies of regeneration ecology, tree silvics, and the influence of silvicultural treatments on forest dynamics can provide good information for fuels managers. Ground disturbance is a form of site preparation that has long been used by silviculturists to naturally regenerate seedlings (Smith and others 1997; Nyland 2002). The same information that underpins silvicultural regeneration practices can be utilized by fuels managers inversely: selecting treatments that minimize the recruitment of seedlings (or ladder fuels). The silvics of western tree species, and their responses to disturbance, have been documented in many places, including several compilations (for example, Barrett 1995; Burns 1983; Burns and Honkala 1990a, 1990b).

Fuel treatments directly affect the recruitment of ladder fuels by the extent to which bare mineral soil is exposed. Treatments that burn or scarify the forest floor will generally result in the accelerated recruitmentof new ladder fuels. Commercial thinning, for example, scarifies the forest floor and provides a mineral soil seedbed that enhances ponderosa pine seedling germination and survival (Oliver and Ryker 1990), increases light to the forest floor that facilitates litter decomposition, and enhances the growth and fecundity of residual trees that can result in greater seed production.

The types, intensities, and spatial arrangements of fuel treatments will determine whether seedling recruitment occurs either in a pulse or is protracted in stages. They also determine whether seedling recruitment occurs in patches or at high densities with spatial continuity. As a rule, fuel treatments that result in rapid pulse recruitment also result in high seedling densities and spatial continuity. Hence, mechanical and prescribed fire treatments that result in greater ground disturbance will typically result in less longevity than treatments that minimize forest floor scarification. For newer and less conventional treatments, the effects on these factors are unclear. It is still uncertain, for example, whether mastication enhances or delays ladder fuel recruitment (Battaglia and others 2010).

Fire models tend to ignore the effects of the specific treatment implementation technique and contract specifications. Aside from the prescription, the specific techniques that are used to implement treatments have their own direct impacts on fuel dynamics, particularly fuels recruitment, which are not represented in models. In the case of mastication, for example, contract specifications vary by project, as do operator skill and mastication equipment type, influencing both the chip size and distribution and the level of post-treatment soil exposure. FFE-FVS can be customized to reflect anticipated changes in stand development associated with these site-specific project outcomes, but such customizations require user understanding of vegetation dynamics and some tweaking of model assumptions.

Longevity and the Fire Environment

Like fuels, the fire environment is dynamic. It is affected by stand structure and changes over time in sync with the changes to stand structure that occur during the course of stand development. Treatments that alter fuel structures also change the fire environment and change the trajectory of the fire environment as stand structure develops following treatment. Subcanopy wind and solar penetration directly affect elements of the fire environment that affect treatment longevity, including fuel moisture contents, air turbulence, and midflame windspeeds.

The effect of moisture content on the availability of dead surface fuels is well understood by fire managers (as is the concept of "moisture of extinction" or the point at which a fire will not spread). The effect of moisture content in live fuels is perhaps less understood, but those moisture contents determine live fuel availability and potential fire behavior. In a modeling study of the sensitivity of surface fire to live fuel moisture, Jolly (2007) demonstrated that fire behavior characteristics are highly sensitive to live fuel moisture. In the aerial fuel complex, the foliar moisture content (FMC) of tree crowns is a known determinant of crown fire behavior (van Wagner 1977). Studies of North American conifers have demonstrated that FMC differs among species, varies seasonally, and sometimes differs between old and new foliage (Agee and others 2002; Keyes 2006). But it appears that the effects of different fuel treatments on those moisture content trends have not been investigated. Studies of the effect of different fuel treatments on moisture contents are needed in order to account for this factor when modeling treatment effects on potential fire behavior.

Longevity and Rates of Change in Live Fuels

Treatment longevity is fundamentally controlled by site quality, which drives rates of change that occur among fuel structures. As a rule, treatment longevity is greatest at less productive sites where changes to forest vegetation occur slowly, and is least at highly productive sites (Weatherspoon and Skinner 1996). In general, growth processes occur more rapidly in dry mixed conifer forests than in dry ponderosa pine forests, and fuel treatment longevity can be expected to be shorter than that of similar treatments applied to drier ponderosa pine forests. The rate at which vegetation grows following fuel treatments is fairly predictable, having been the subject of growth and yield studies for decades. That rate is directly proportional to the quality of the site. For fuels managers, several familiar proxies representing the cumulative factors contributing to site quality exist in the traditional measures of site and can be useful as longevity indicators, i.e., (1) site index and (2) habitat types. Site index and habitat types (or plant associations) provide a useful coarse method of categorizing anticipated treatment longevity among sites.

Site index is a measure of site quality as expressed by the height growth of trees over time. Because height growth is relatively independent of stand density, the quality of a site is revealed primarily in the observed rate of height growth. Site index curves have been developed across the range of dry mixed conifer forest types. Examples include curves by Barrett (1978) for the interior Pacific Northwest, by Krumland and Eng (2005) for northern California, and by Milner (1992) for western Montana (see Chapter 2). In most regions within the dry mixed conifer range, fuels managers will use site index when using Forest Vegetation Simulator (FVS), as that metric is the driver of stand growth and the changes to canopy fuels in the Fire and Fuels Extension (FFE). But fuels managers can apply site index (using local site curves and basic stand data) to map site quality of stands within landscapes, and thereby classify rates of fuel longevity over large areas.

Throughout the range of dry mixed conifer forests, but perhaps most notably in the northern Rocky Mountains, habitat types are used more commonly than site index to communicate both potential vegetation and site quality. Habitat types are not forest cover types, which describe the current canopy species composition of a stand. Rather, they are classes that indicate sites of similar potential, (or climax vegetation communities (Daubenmire 1966).

The terminology may vary from place to place. For example, at central Oregon's Warm Springs Reservation, "plant associations" rather than habitat types are available (Marsh and others 1987). But insofar as they describe potential vegetation, they allow for comparisons of site quality within regions. Examples include the habitat types by Pfister and others (1977) for Montana, Williams and others (1995) for northeastern Washington, and Cooper and others (1991) for northern Idaho. Since potential vegetation is tied to the same environmental gradients that determine vegetation growth, habitat types are useful indicators of site quality as well. In the northern Rocky Mountains, habitat types are such a dominant descriptor of site quality that they are utilized as the drivers of growth within the region's FVS variants, rather than site index. For fuels managers, mapping dry mixed conifer forests by habitat type offers another way of categorizing post-treatment fuels growth and treatment longevity. To identify locally relevant systems of habitat types, fuels managers can consult the useful listing of forest habitat types prepared for Rocky Mountain forests by Alexander (1985).

Longevity and Decision Support Tools

Longevity is poorly represented in fire simulation tools. Some models can examine fuel longevity, but many sub-models must be synthesized into one comprehensive measure of fuel projection changes over time in order to scale up to address questions of treatment longevity at stand scales. As Fernandes (2009) noted, "fire simulation…rests more on theory than on sound field data." The model most appropriate for the task is FFE-FVS (Reinhardt and Crookston 2003), which links forest stand growth and fire behavior models. However, many important components of change that affect longevity are not adequately represented in the model by stand-level treatments, including decomposition models, regeneration recruitment and growth models, and crown expansion models. All require calibration with local values.

Existing decision support models are poor predictors of ladder fuel recruitment. Although FFE-FVS projects tree and stand growth reasonably well, depending on the variant, the model poorly predicts natural regeneration patterns that result in ladder fuel recruitment. Without calibration and variant specific regeneration modules, it will exaggerate ladder fuel development and underestimate treatment longevity. Hence, when using FFE-FVS it is vital to understand the model, both its features and limitations, and apply it properly. Training modules are available to understand and use fire behavior models, including FFE-FVS, as are staff and support at the Forest Service Management Center (http://www.fs.fed.us/fmsc/index.shtml).

Some useful models of ladder growth development exist, and others are being developed. In California, growth models of seedlings and saplings in dry mixed conifer stands have been in development for more than a decade (SYSTUM-1 by Ritchie and Powers 1993). The motivation stemmed from an interest in quantifying the effects of site preparation practices on regeneration growth rates, with the goal of enabling managers to better select from treatment alternatives. This topic is the primary focus of modeling efforts by the Inland Empire Growth and Yield Cooperative (J. Goodburn, personal communication) and should soon be implemented in the regional variants of FVS, which would result in better fire behavior projections over time in FFE. Whether the same progress is being made in other regions where dry mixed conifer forests exist is unclear.

Opportunities exist to improve empirical treatment longevity models for western forests. The appropriateness of linking multiple submodels for fire simulation already remains somewhat in question (Cruz and Alexander 2010), and adding models of temporal change to fuel and fire prediction models magnifies that concern. Yet, further refinement of those submodels and input parameters is possible. At the Fire and Fire Surrogates study installations, for example, only the immediate post-treatment effects of thinning, burning, and thinning-burning treatments have yet been reported (Stephens and others 2009). But that replicated, multi-site study provides an excellent foundation for testing the longevity of those common fuel treatments.

Silvicultural trials provide untapped opportunities for improving longevity models. Long-term silvicultural thinning trials with long data records exist throughout major forest types of the western United States, including ponderosa pine, for a range of stand ages, compositions, and densities (varying by location). Since thinning (commercial and pre-commercial) is a common fuel treatment, these can serve as excellent laboratories for understanding the effect of thinning on fuel attributes over time. For example, the original purpose of the West-wide LOGS studies was to investigate the effect of thinning intensity and post-treatment tree spacing on stand growth (Oliver 2005). The LOGS plots have been much studied, but they have not been utilized for the study of fuels dynamics. They can be readily exploited to relate thinning intensity to temporal changes in crown fuel loads, ladder fuels, and surface fuels, as well as subcanopy microclimates that determine midflame windspeeds and fuel moisture contents. Fuels-specific experiments involving common western fuel treatments and treatment combinations provide more opportunities for generating empirical longevity data.

Conclusion

Fuel treatments can appear static, but they create fuel structures that are highly dynamic. That dynamism ensures that treatment alternatives will differ not only in their immediate effect on potential fire behavior but in their longevity or persistence as well. In the days and years following treatment, dead fuels degrade and aggrade; existing live fuels grow and new live fuels are recruited; some live fuels convert to dead fuels; and the horizontal and vertical arrangements of all fuel layers change. The changes to fuel structures are a function of pre-treatment condition, post-treatment condition, site productivity, and time. Recognizing those elements that contribute to treatment longevity during the planning process will help result in the selection of treatments and treatment combinations that have enduring effects.

How is it possible to integrate all the elements of treatment longevity in decision-making? One way is in a visual ranking format that synthesizes elements of longevity in that rank. Quantifying years of longevity remains challenging to current modeling capabilities, but it is feasible to rank a project's treatment alternatives by the post-treatment environments they create. Figure 12.6 presents an example of one possible ordinal ranking system, with cutting intensity and spatial arrangement serving as the primary longevity criteria. In this example, treatments affect torching potential (initiation of crown fire from surface fire) and crowning potential (spread of crown fire following canopy ignition) differently, and with longevity tradeoffs between them; hence, scores (1 to 9) are assigned for each of those elements. The photos in fig. 12.7 accompany the fig. 12.6 ranking system and portray examples of possible fuel treatments resembling thinning, shelterwood or seed tree cuts (dispersed retention cuttings), and group selection or patch cuts (aggregated retention cuttings). In this framework, high ranks indicate greater treatment longevity (or persistence of treatment effect), with low ranks representing lesser treatment longevity. For example, cuttings that remove more trees and create larger gaps between trees result in greater crowning potential longevity, as it will take longer for the crowns of residual trees to close the gaps between them. In contrast, those same treatments have the least torching longevity since the large gaps facilitate the recruitment and growth of ladder fuels while also halting crown recession of residual trees. The rankings in this schematic are subjective, but this type of ranking system is proposed as a template that fuels managers and researchers can consider and develop further, with adaptations that fit local species, treatment alternatives, and knowledge.

In many cases, the best treatment alternative is a compromise between achieving immediate impacts and achieving results with longevity. As Reinhardt and others (2008) stated, "we must think of fuel treatment regimes rather than single fuel treatment projects." A regime approach to fuels planning will help ensure that fuel dynamics and treatment longevity are addressed in the planning of individual treatments.

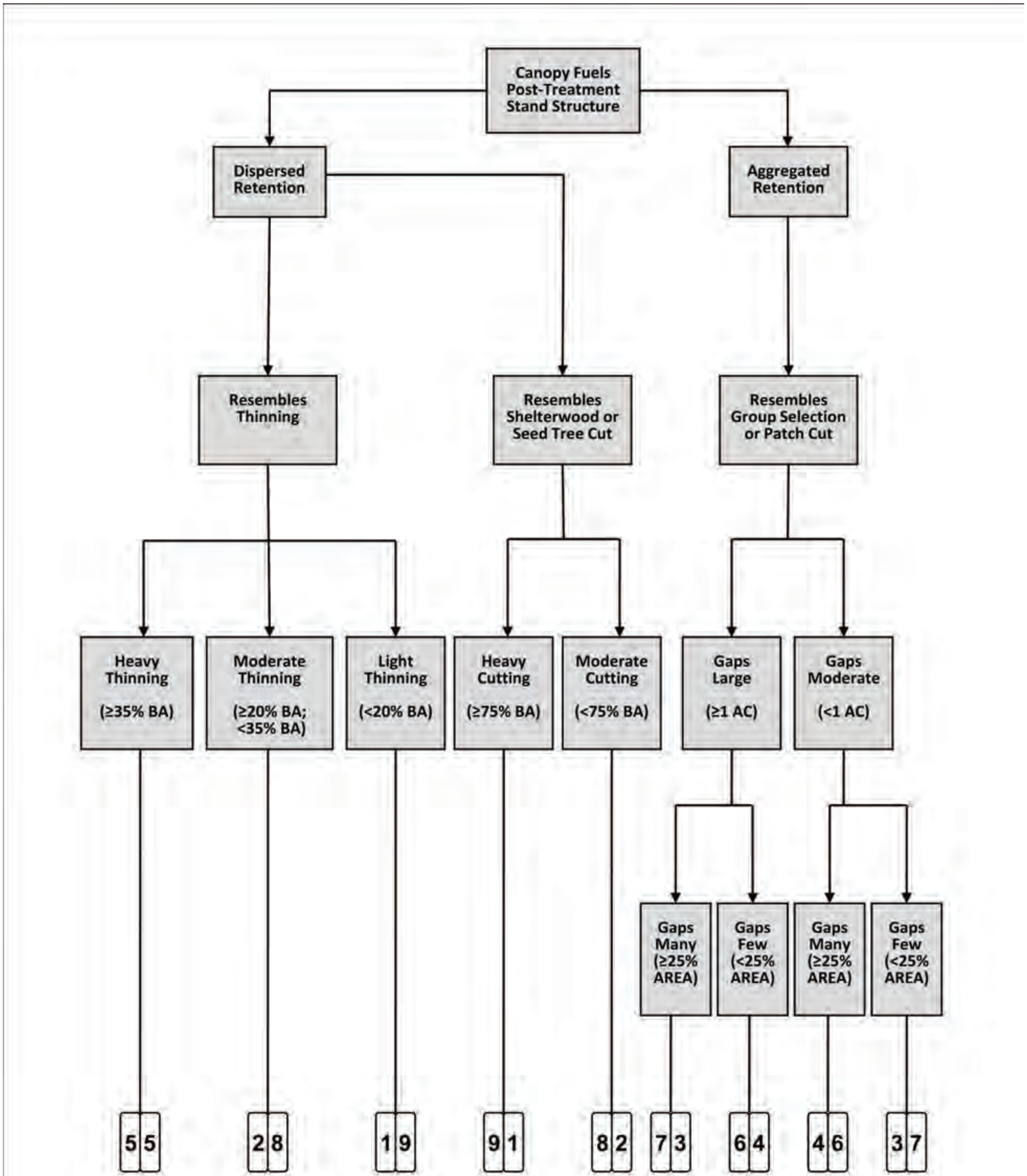


Figure 12.6. Proposed system for ranking different canopy fuels treatment prescriptions on the basis of treatment longevity. Longevity ranks range 1 to 9, with highest values signifying longer persistence of treatment effect. Treatment prescriptions affect trends in crowning potential and torching potential differently; hence, scores are assigned for each of those elements separately (Crowning Potential, left; Torching Potential, right). First decision tier refers to spatial patterns of trees following treatment, from dispersed retention (trees uniformly or randomly spaced) to aggregated retention (canopy gaps and untreated clumps). Second decision tier is the best approximation of the visual appearance of the treatment following implementation. Third decision tier is the relative amount of reduced stand density, represented as percent basal area cut (dispersed retention) or gap size (aggregated retention). Fourth tier (aggregated retention only) is the proportional project area that is represented by clearings (relative to untreated matrix forest).

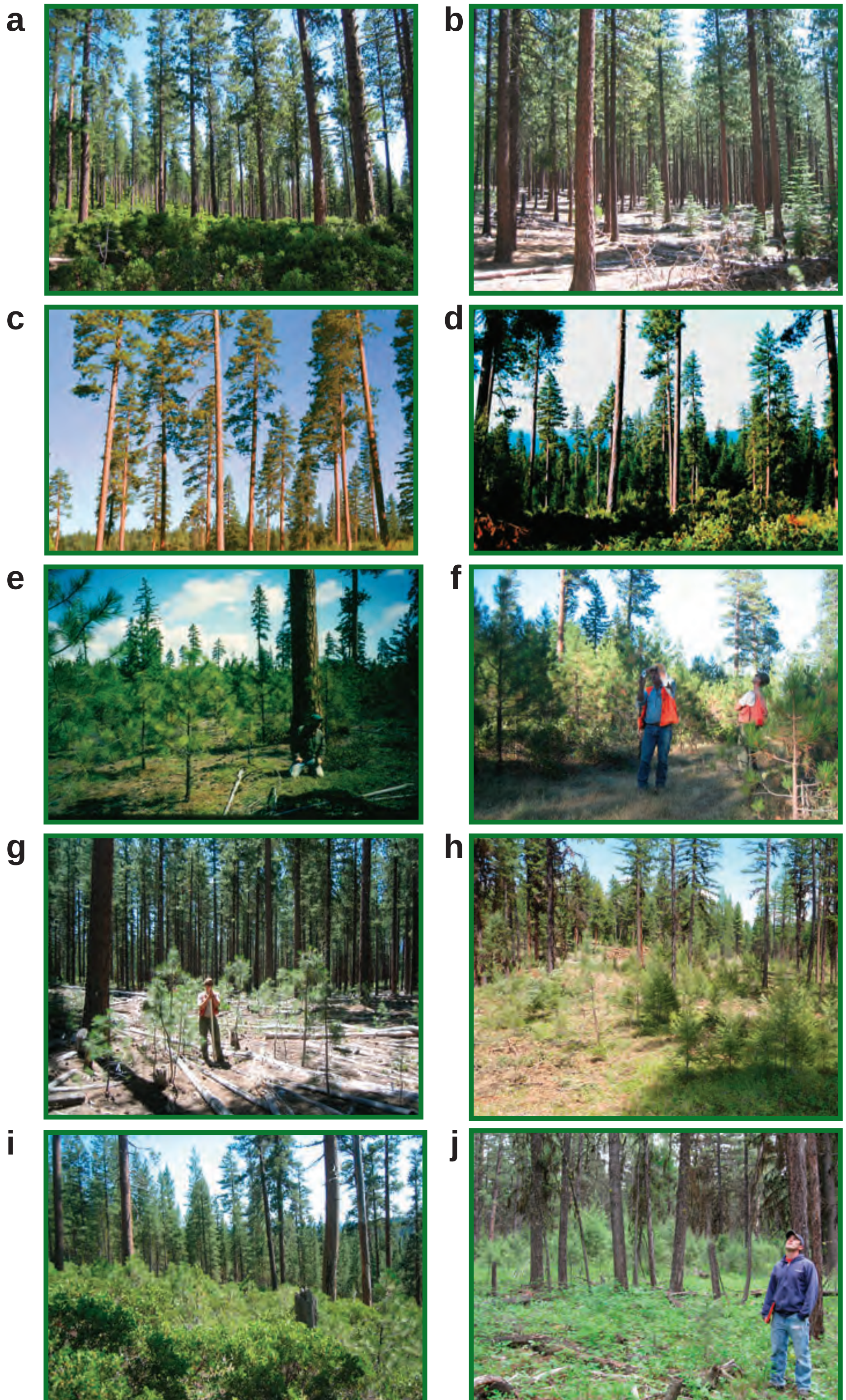


Figure 12.7. Classifying the cutting intensity and spatial pattern/scale in fuels treatments (to accompany fig. 12.6). First row treatments (A, B) are best characterized as thinnings; second and third row treatments are heavier dispersed-retention cuttings that resemble shelterwood cuts (C, D) or seed tree cuts (E, F), respectively. Fourth and fifth row treatments (G-J) are aggregated retention cuts resembling group selection or patch cuts.

Special Feature: An interactive references database is available at: http://www.fs.fed.us/rm/pubs/rmrs_gtr292.html and on the CD accompanying this publication.

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Appendix A: Chapter 5 Supplement

Inventory Modeling of Current Fire Hazard Conditions

In this appendix, we provide histograms of FFE-FVS model-summarized, 2000-2009 Forest Inventory and Analysis data that depict forest structure and fire hazard metrics for the dry mixed conifer forests of Washington, Oregon, Idaho, Montana, Utah, and extreme northern California. The information is intended to supplement Chapter 5 (Inventory Modeling of Current Fire Hazard Conditions) and to provide useful context for planning fuels management throughout the synthesis area. Ordered by region (Northern California and Klamath, Pacific Northwest Interior, Northern and Central Rockies, and Utah), and within each region by forest type group (Douglas-fir and True Fir, Pine and western larch, Aspen/birch, Western Redcedar, and Other), each page summarizes eight attributes for one combination of region and forest type group.

These information-rich histograms provide a statistically unbiased basis for evaluating current conditions, and much can be learned by comparison among regions and forest type groups. We present one set of interpretations for the Douglas-fir and true fir forests in the Northern California and Klamath region as an example of the kinds of interpretation that are possible using this information resource.

In the left side of each page, the stand structure attributes QMD (quadratic mean diameter, in inches), TPA (trees per acre), BA (basal area in ft^2), and Canopy Cover (percent canopy cover, as calculated via FVS) are summarized as frequency histograms. FFE-FVS-estimated fire hazard attributes are summarized on the right side of each page: surface flame length (predicted height of flames from combustion of surface fuels under extreme conditions), torching index (wind speed, in miles per hour, at which torching behavior would be expected), mortality volume percent (percent of the timber volume predicted to convert from live to dead given an extreme fire), and crowning index (wind speed, in miles per hour, at which active crown fire behavior would be expected). Each histogram describes the relative frequency of each attribute level for the region and forest type group represented on that page. The Y-axis represents the proportion of forest area in one subregion/forest type group combination. These can be easily translated into acres, if desired, by multiplying the proportions by the area (in acres) printed in the text block included in each histogram.

Each subfigure containing a histogram also contains a printed mean and a rough approximation[1] of the sampling error (SE) for the attribute. Sampling errors tend to be smaller as area represented (and the associated sample size) increases. The true (population) mean has a 95 percent chance of being contained by the interval constructed as the sample mean +/- 2 times the sampling error. In some cases, the X-axis of the histogram is truncated and the last histogram bar on the X-axis represents a larger range than the other histogram bars, and the last X-axis label is modified accordingly.

[1] These sampling errors do not account for the different landscape weights (acre expansion factors) associated with each forested condition; they also do not reflect any error or uncertainty associated with models used to generate estimates of, for example, volume or surface flame height.

Note that histograms are only plotted for cases where there are at least 10 conditions for a subregion/forest type group combination. It is inadvisable to attempt inferences from fewer than 10 conditions, and some analysts are more comfortable with a sample size minimum of 30.

Example Interpretation of Histograms for the Northern California and Klamath Subregion's Douglas-fir and True Fir Forests

There are approximately 1.1 million acres of Douglas-fir and true fir forests in this subregion. Four structure attributes and four fire hazard attributes provide key insights into current hazard and opportunities for promoting resilience and reducing hazard.

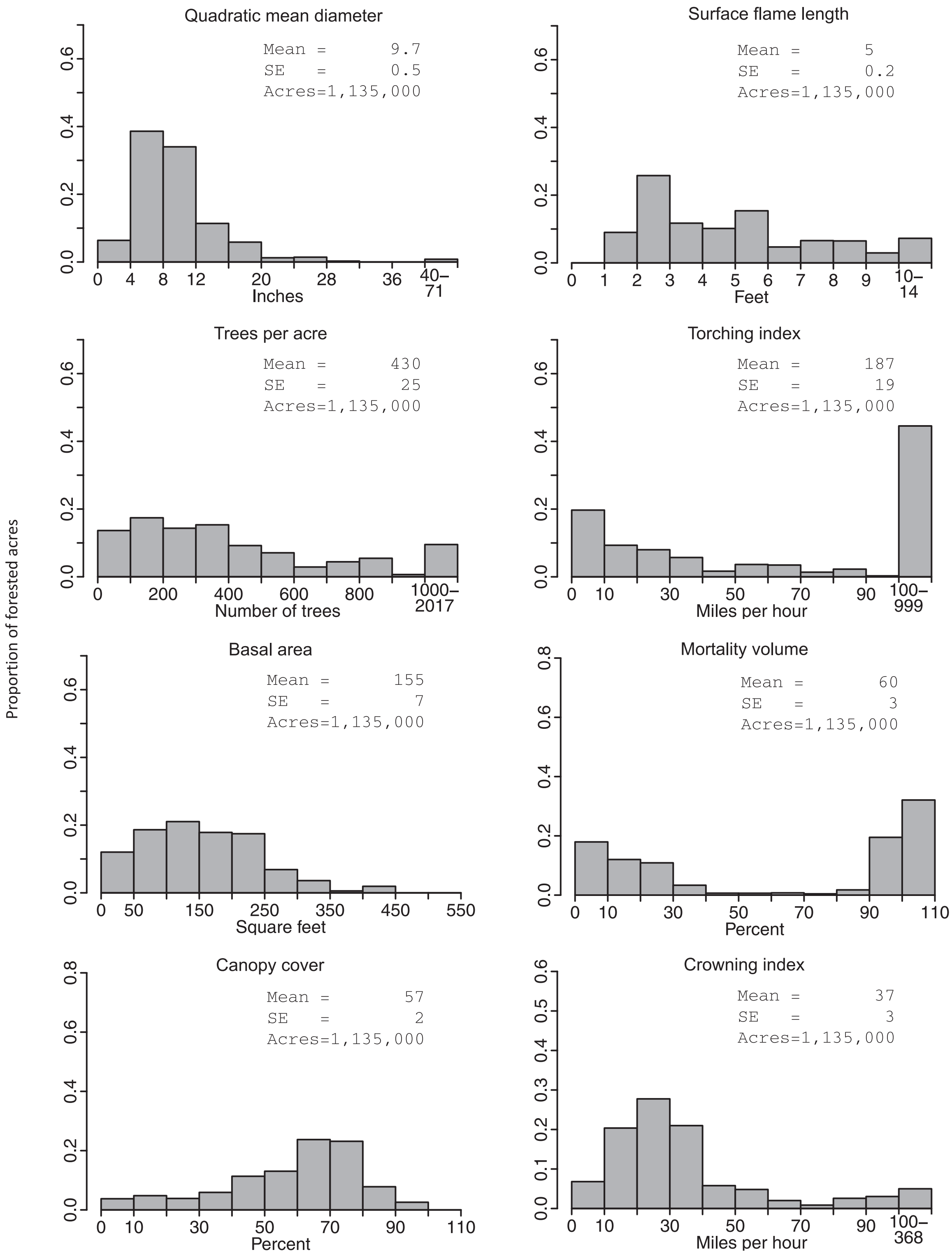
Forest characteristics

Mean QMD of these forests is relatively small (under 10 inches dbh), and nearly 50 percent have a QMD of <8 inches. However, in a small proportion of the area (< 2 percent), stands are dominated by large trees such that QMD exceeds 40 inches dbh. About half of the area has less than 400 TPA, but 8 percent has densities over 1000 TPA. Most stands have a basal area (BA) between 50 and 250 (mean is 155) ft^2 $acre^{-1}$, though there are a few instances of BA exceeding 400 ft^2 $acre^{-1}$. Canopy cover tends to be high, with a mean at 67 and a mode between 60 and 80.

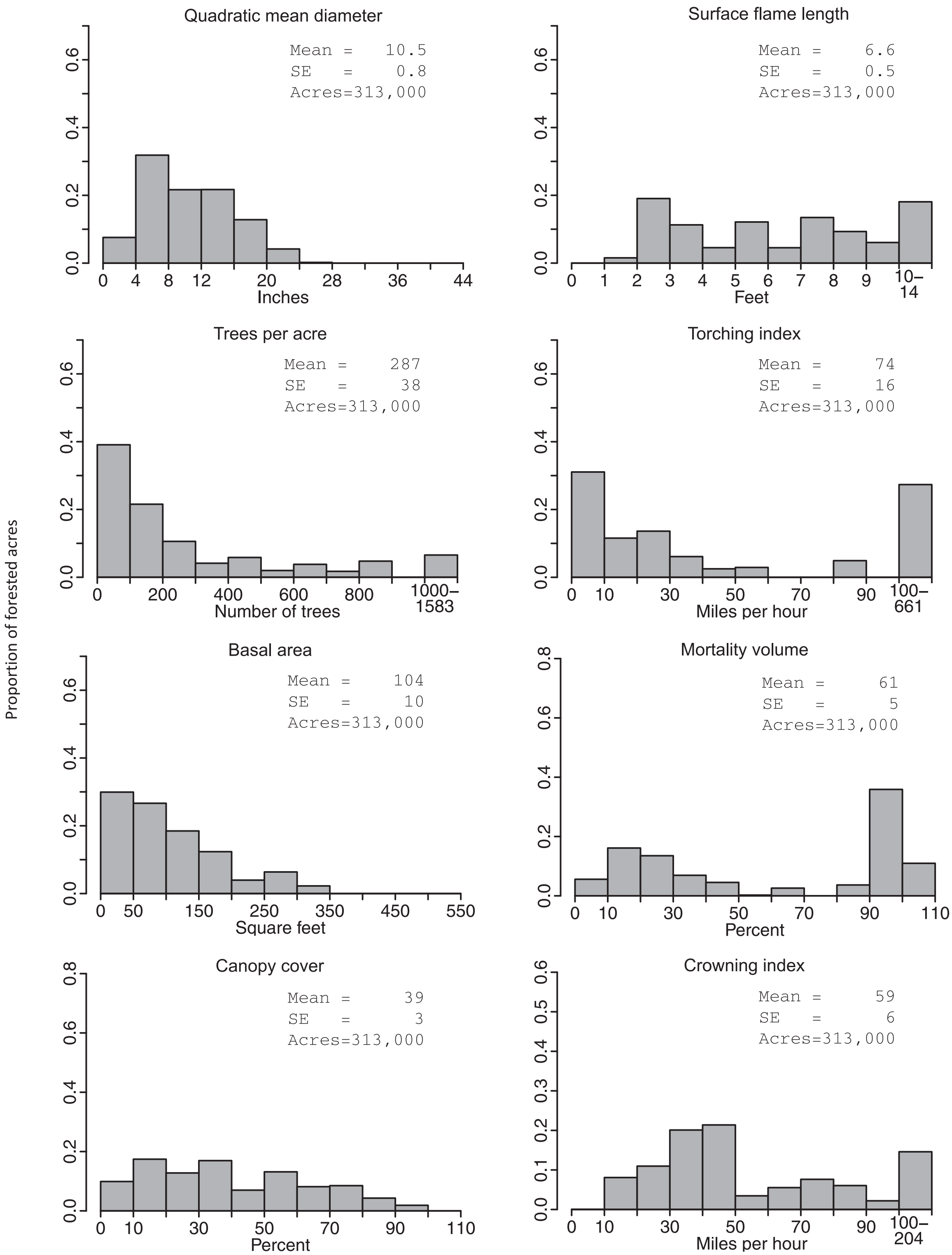
Fire characteristics

Surface flame lengths vary widely with the great majority of the conditions expected to have a flame length under 6 ft. Torching index is low in a large proportion (40 percent) of the area (i.e., less than 30 mph). However, another 40 percent of the area has torching indices in excess of 100 mph, such that even relatively high intensity surface fires could be expected to incur minimal torching. Due to species composition in these stands (for example, tolerant vs. intolerant), mortality from a wildfire, while averaging 60 percent, has a bimodal distribution (most values are well below or above the mean). Approximately 50 percent would have >90 percent mortality and another 50 percent would have less than <30 percent. Consistent with the prevalence of high canopy cover, the majority (>50 percent) of the forests have crowning indices under 30 miles per hour (mph).

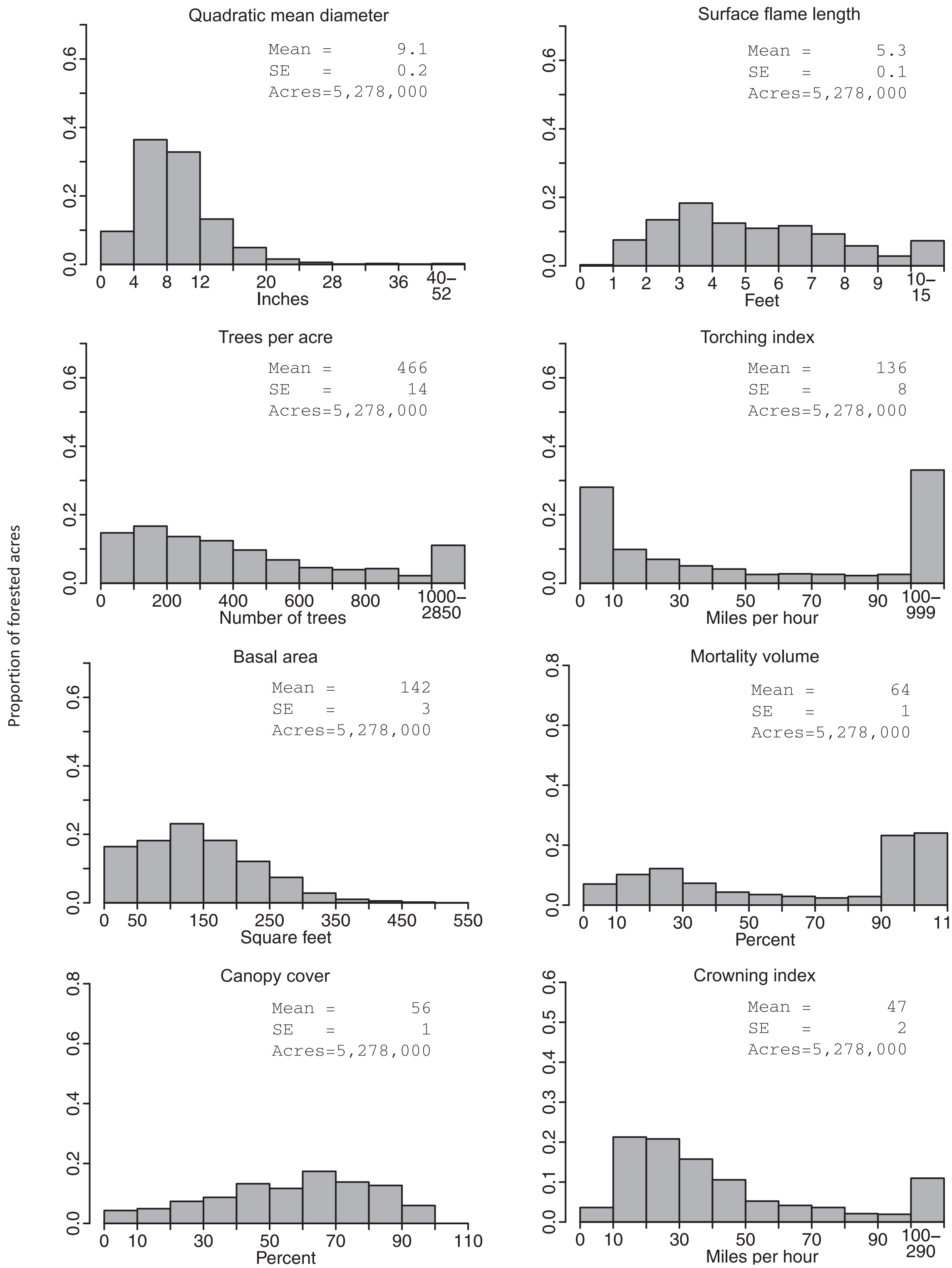
Northern California and Klamath - Douglas-fir and True Fir



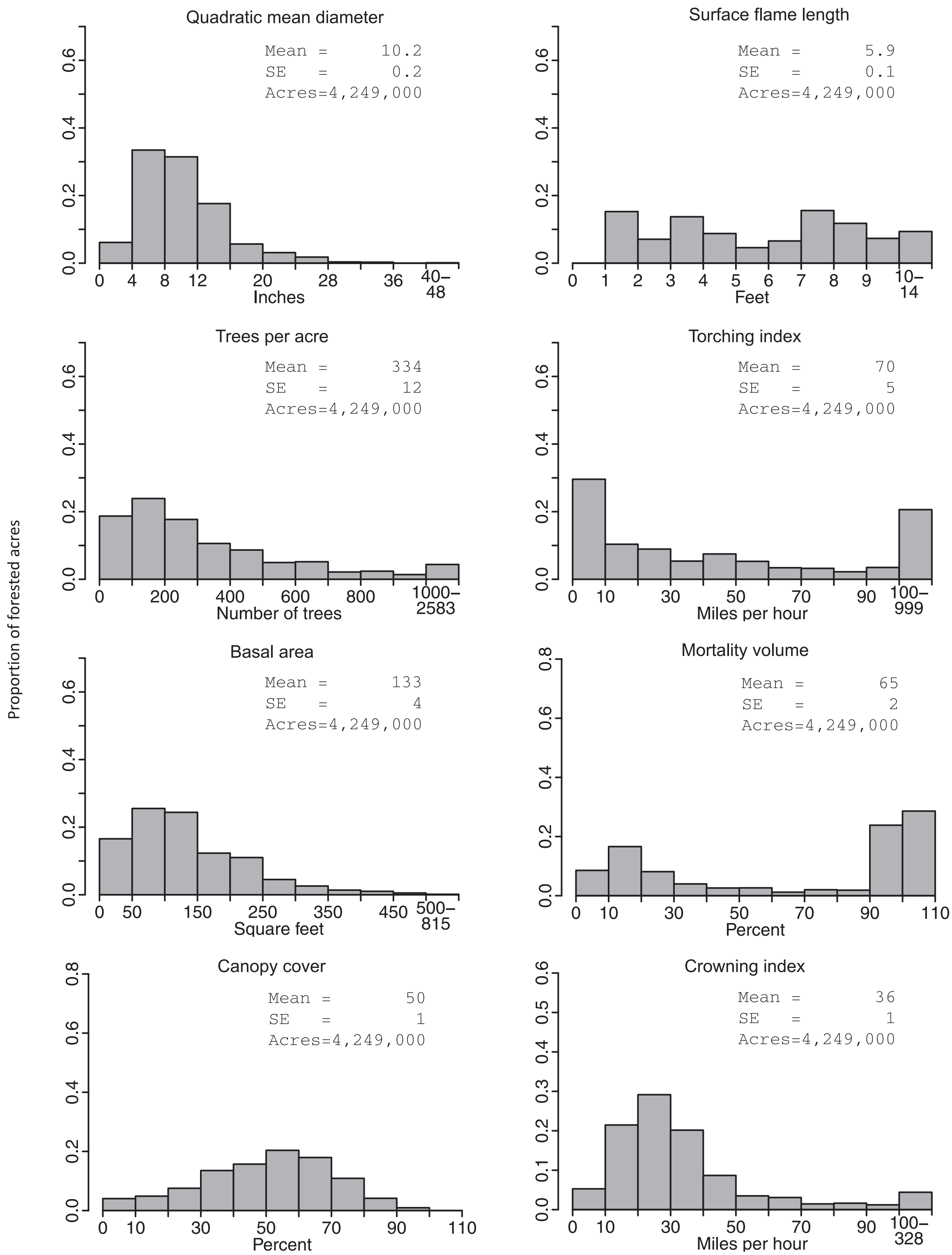
Northern California and Klamath - Pine and Western Larch



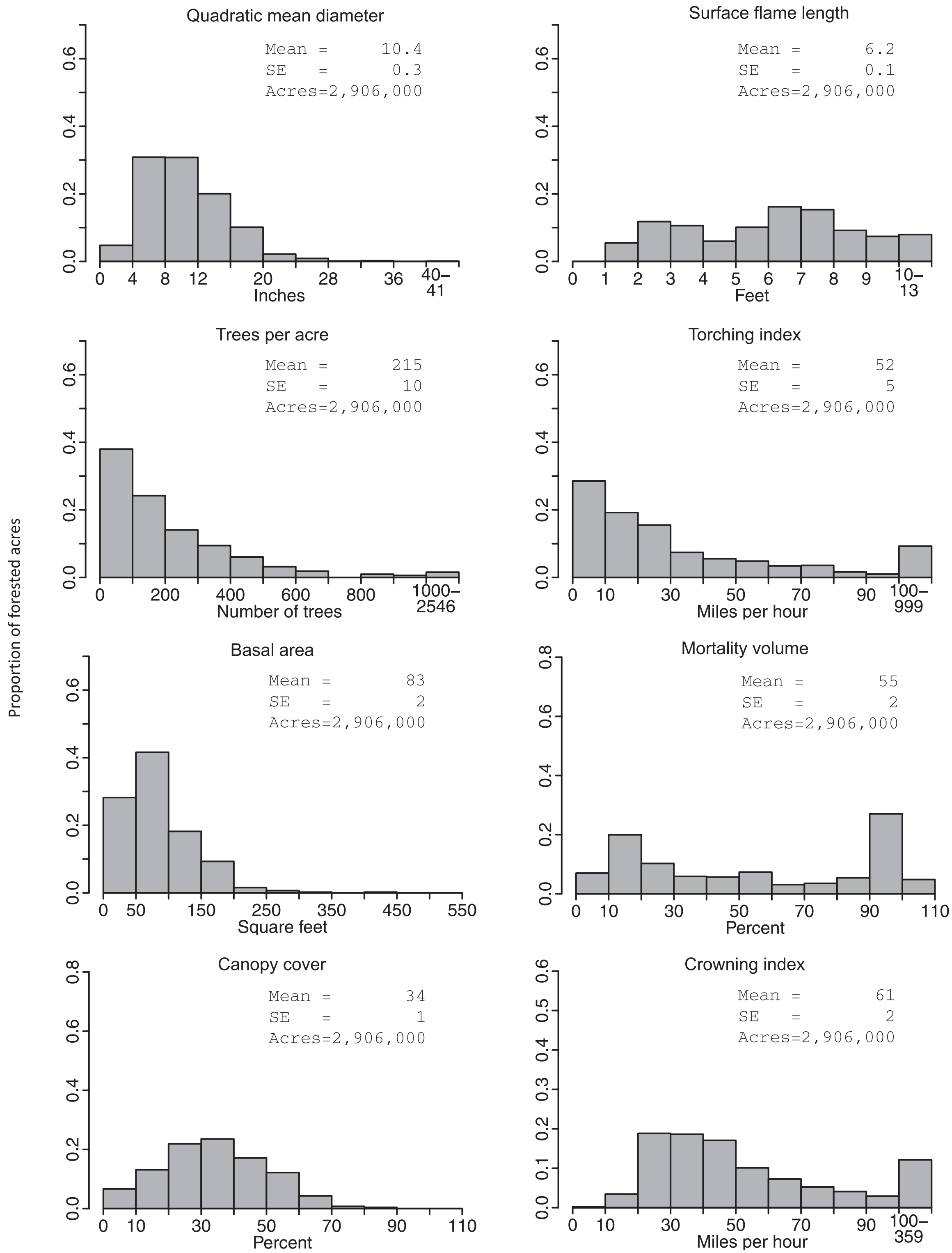
Northern California and Klamath - Other Species



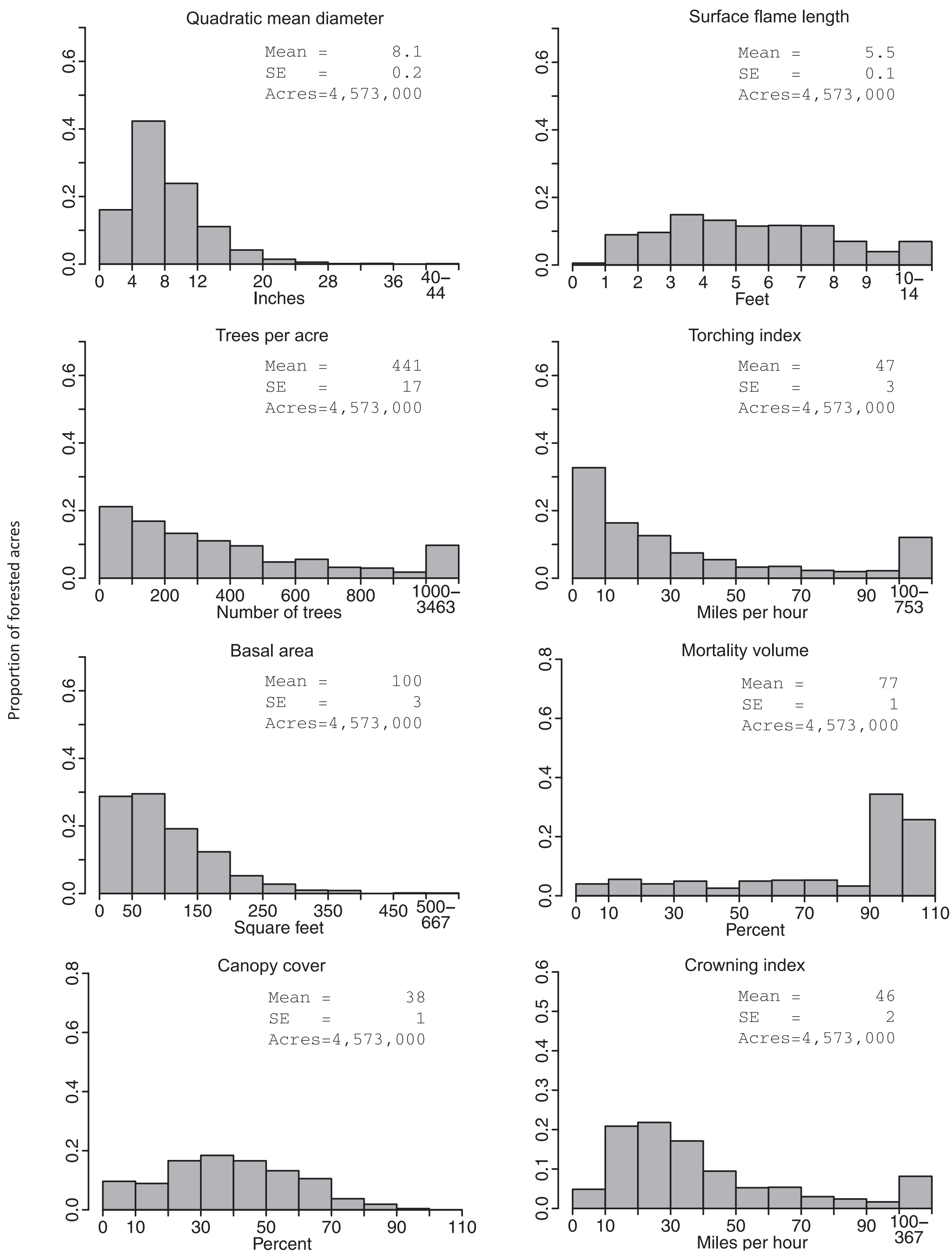
Pacific Northwest Interior - Douglas-fir and True Fir



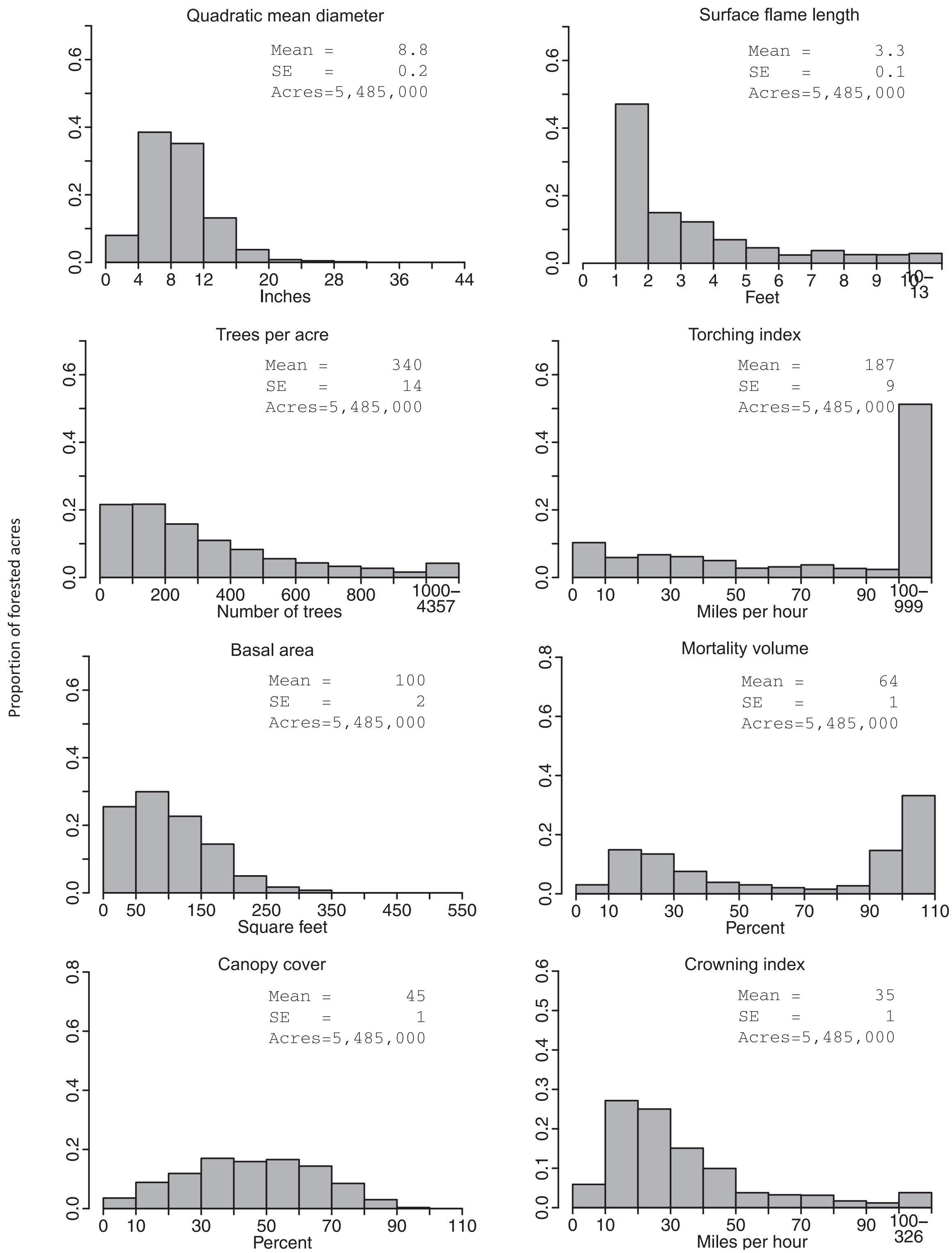
Pacific Northwest Interior - Pine and Western Larch



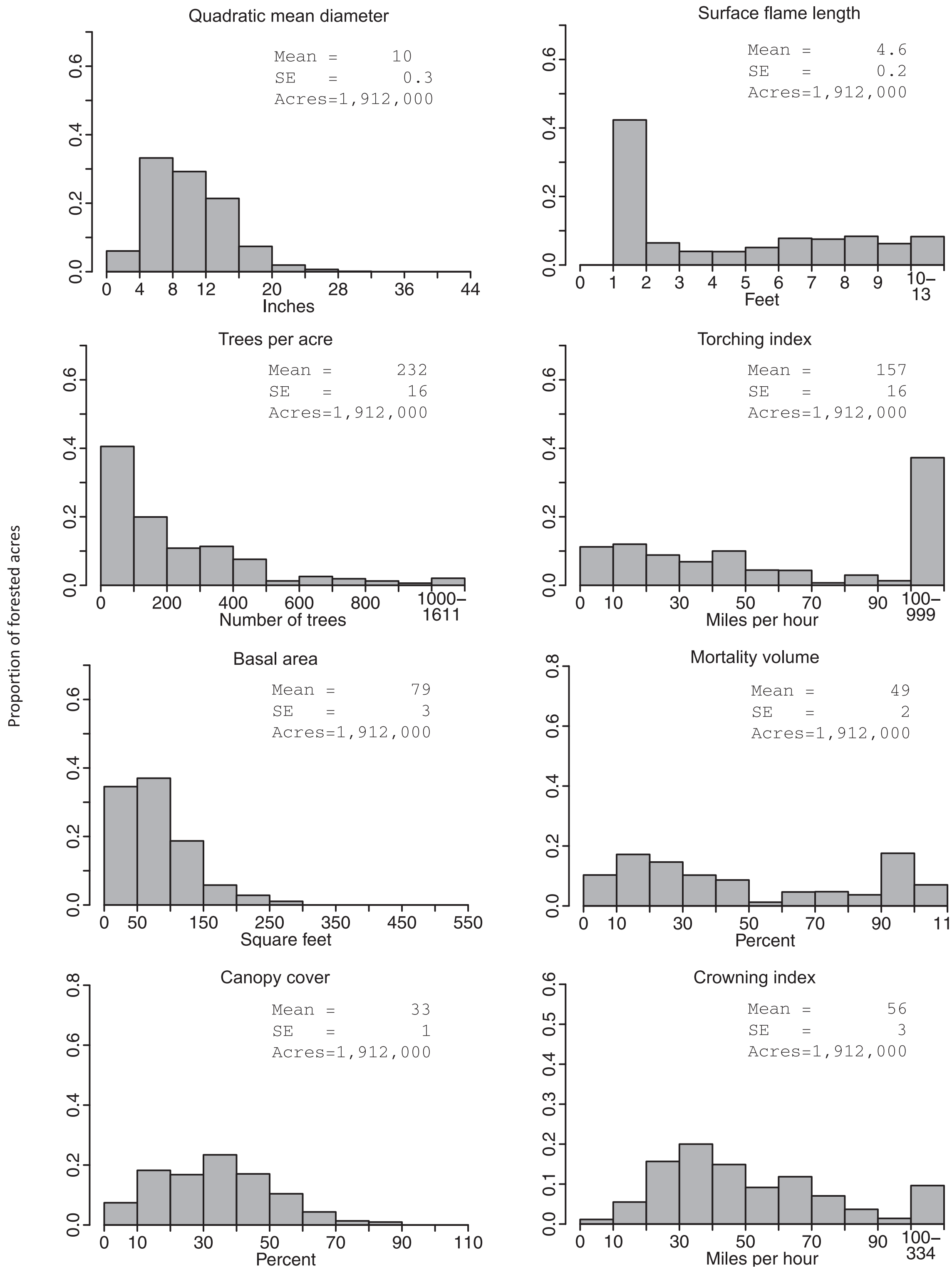
Pacific Northwest Interior - Other Species



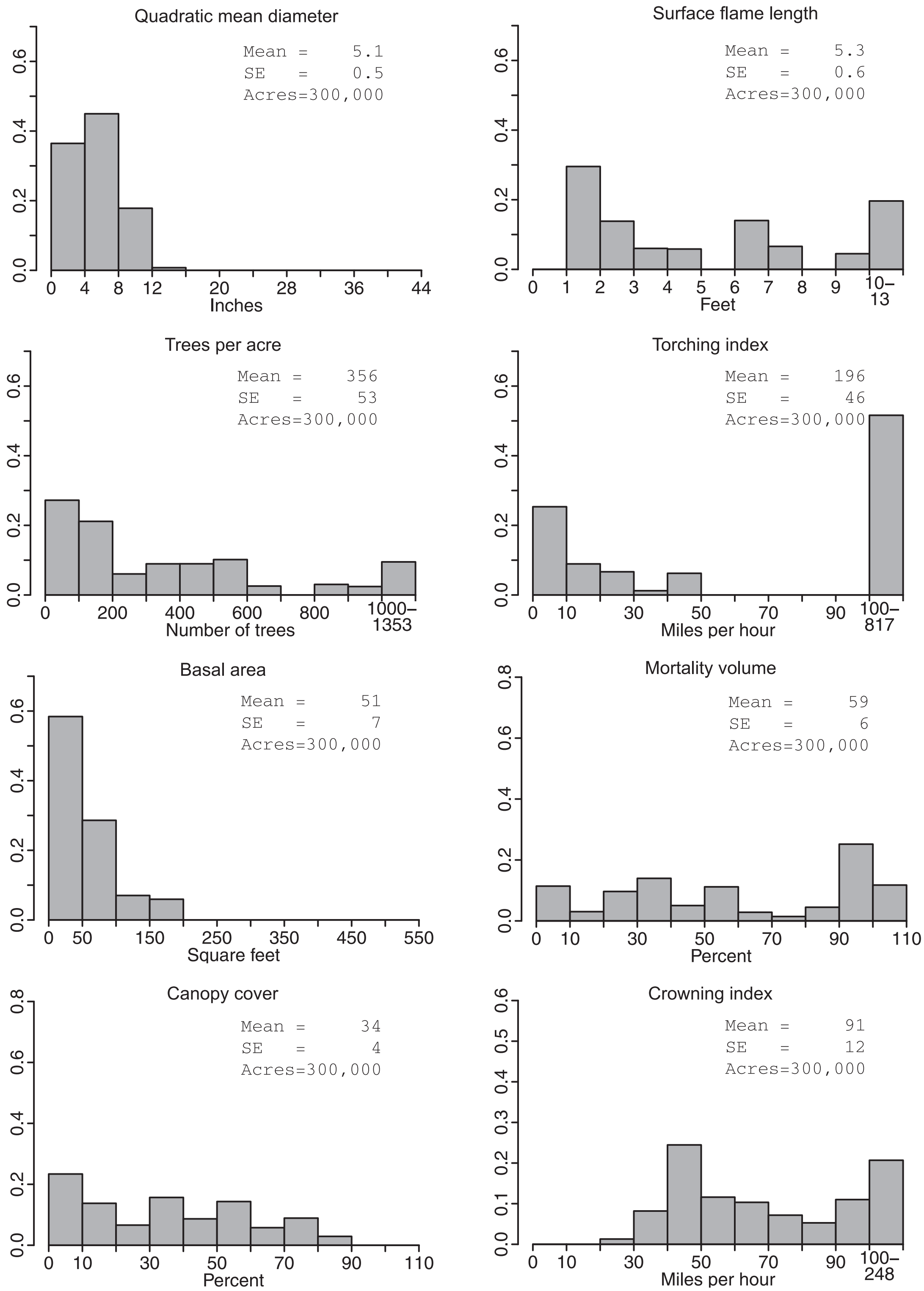
North and Central Rocky Mountains - Douglas-fir and True Fir



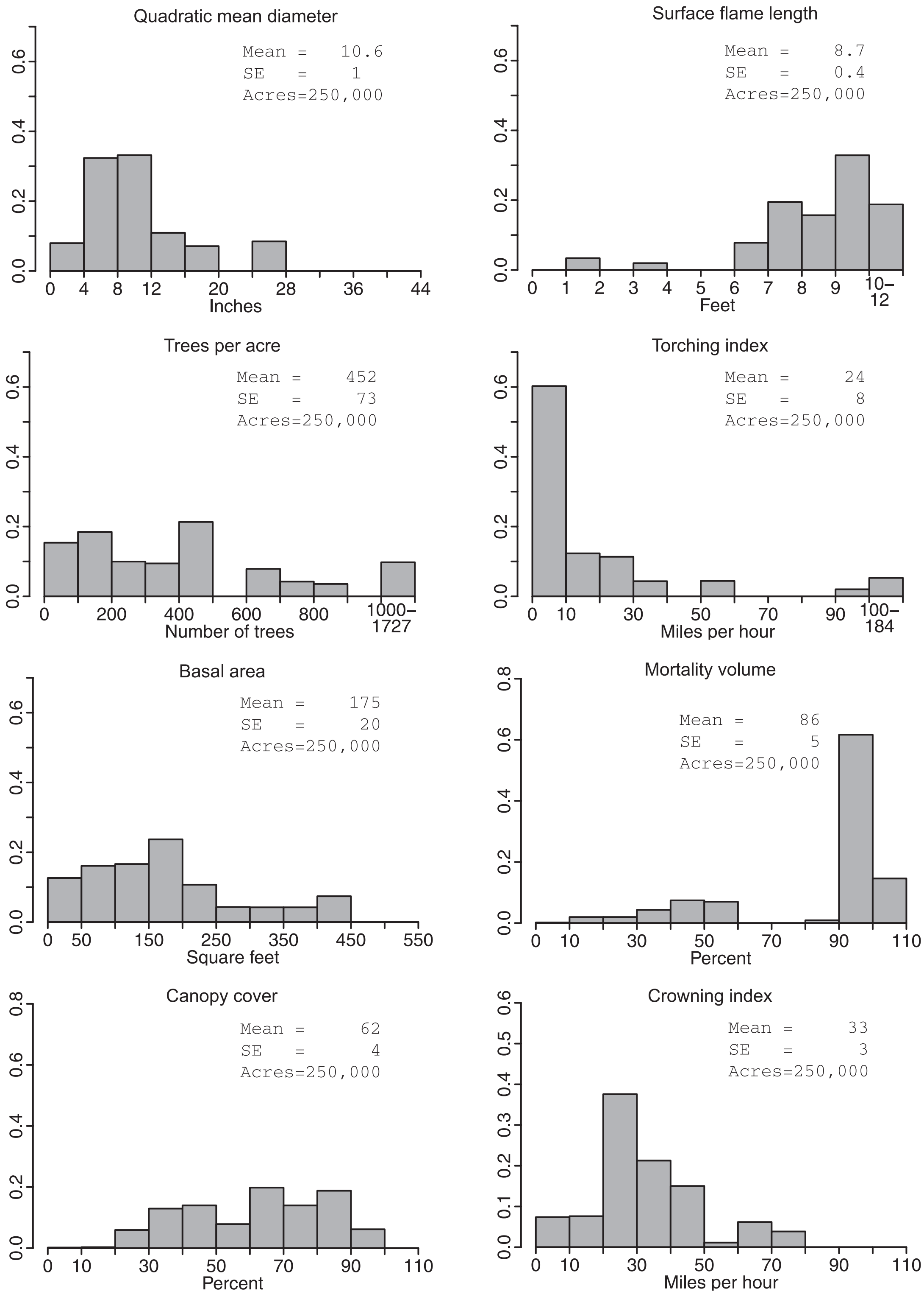
North and Central Rocky Mountains - Pine and Western Larch



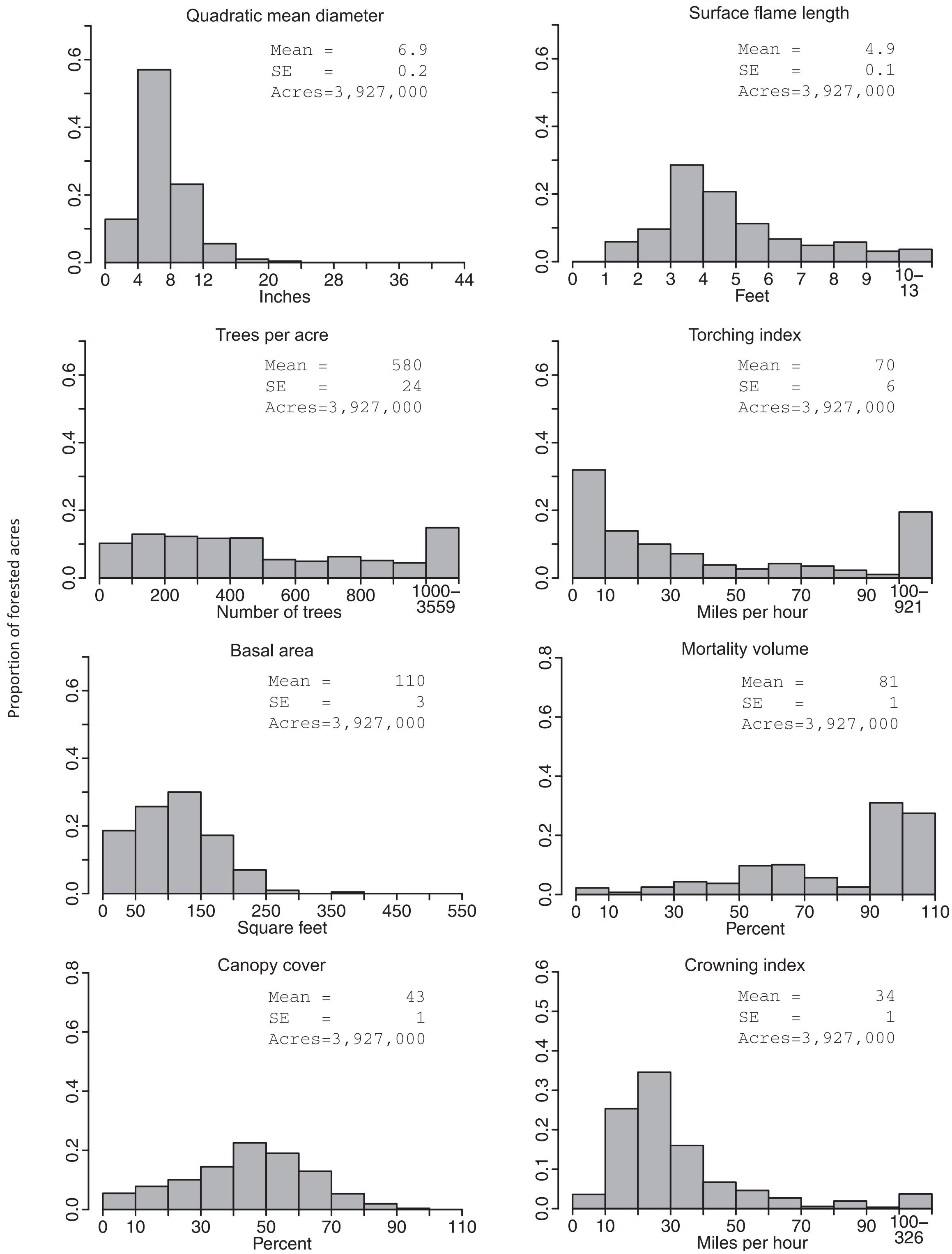
North and Central Rocky Mountains - Aspen



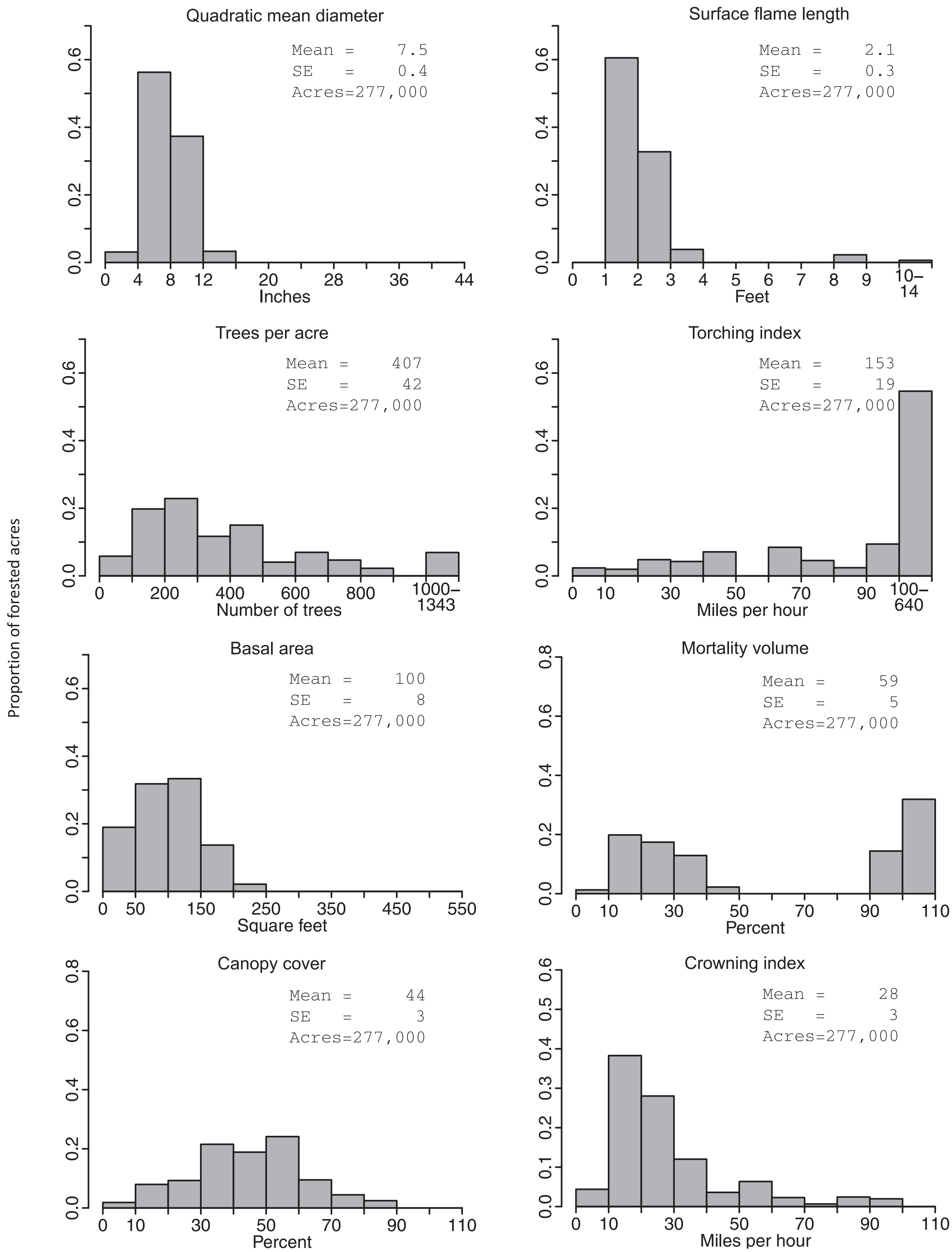
North and Central Rocky Mountains - Western Redcedar



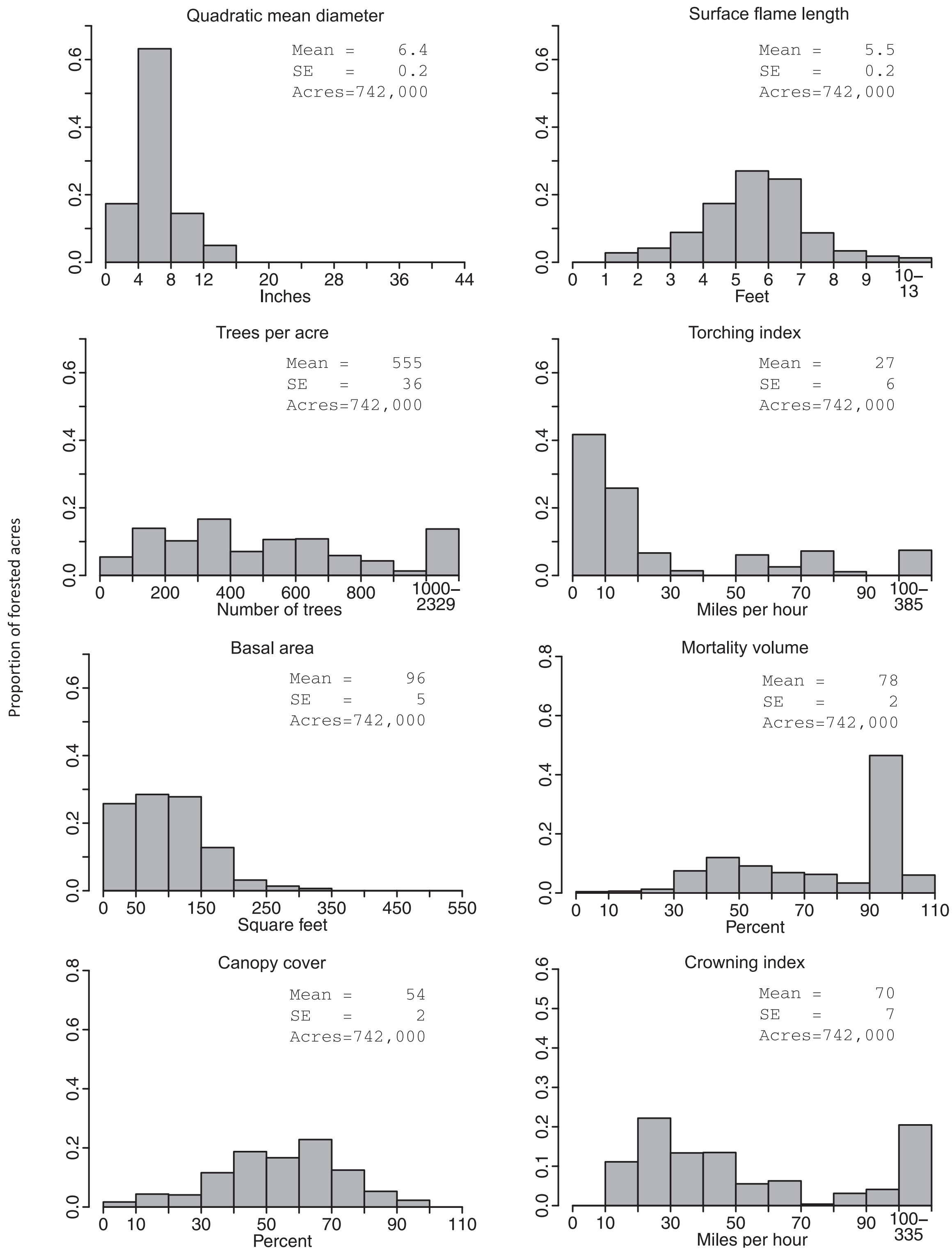
North and Central Rocky Mountains - Other Species



Utah - Douglas-fir and True Fir

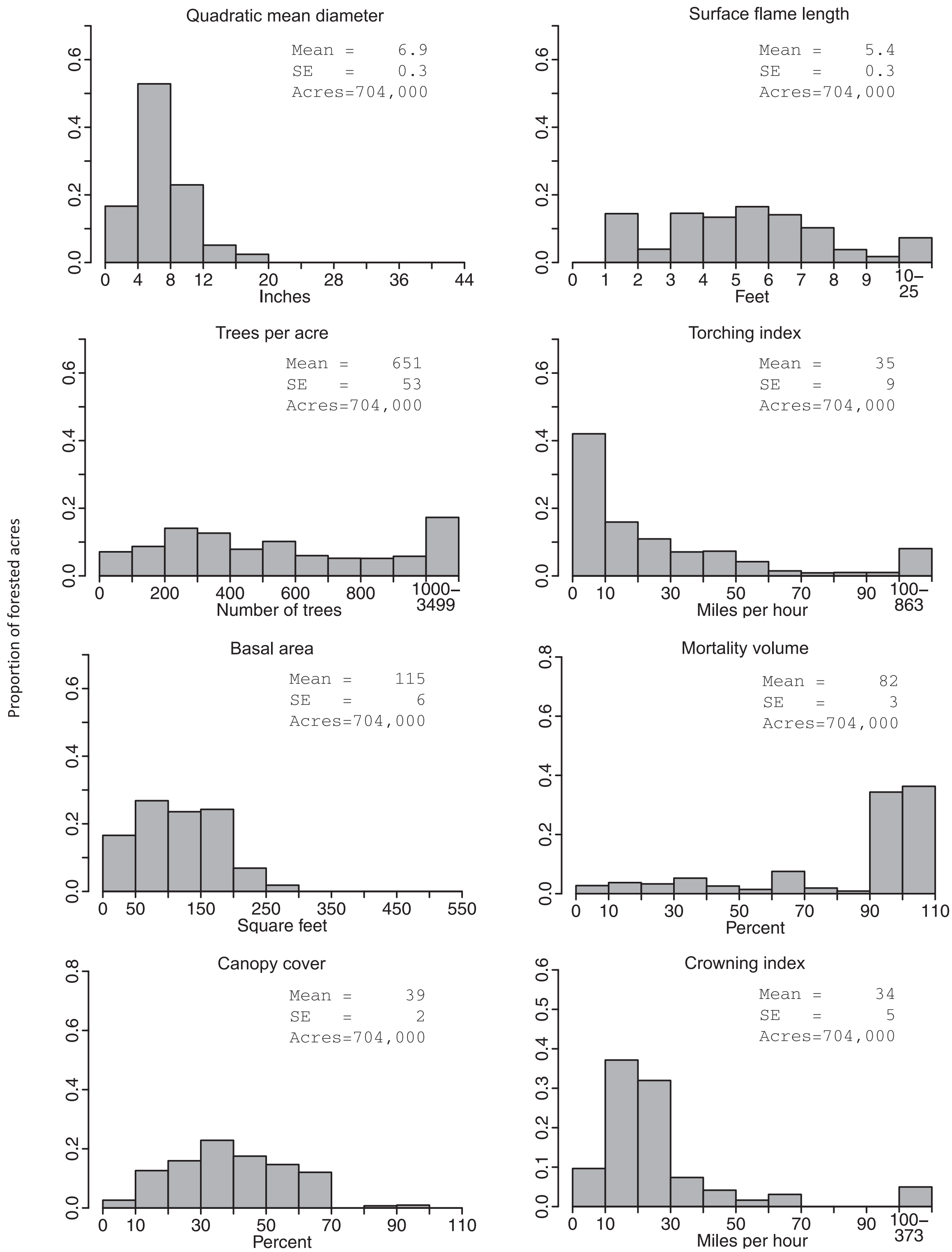


Utah - Aspen



Proportion of forested acres
Quadratic mean diameter
Mean = 6.4
SE = 0.2
Acres=742,000
Inches
Surface flame length
Mean = 5.5
SE = 0.2
Acres=742,000
Feet
Trees per acre
Mean = 555
SE = 36
Acres=742,000
Number of trees
Torching index
Mean = 27
SE = 6
Acres=742,000
Miles per hour
Basal area
Mean = 96
SE = 5
Acres=742,000
Square feet
Mortality volume
Mean = 78
SE = 2
Acres=742,000
Percent
Canopy cover
Mean = 54
SE = 2
Acres=742,000
Percent
Crowning index
Mean = 70
SE = 7
Acres=742,000
Miles per hour

Utah- Other Species



Appendix B: Decision Support Tools for Managers

Manager comment: There is an abundance of decision support tools; the challenge is finding the time to investigate, learn, and use all that is available.

There is an abundance of decision support models designed to provide scientific and technical support to inform decision-making (summarized by Peterson and others 2007; Stratton 2006). Although managers recognize the value of decision support tools, they often do not have the time to become proficient using the tools or do not know which is the most appropriate for a given need. In our interviews, we found that a specific set of models are recognized and used, typically these more popular decision support tools are supported nationally and have technical support to maintain the model's integrity.

We encourage reviewing both Peterson and others (2007) and Stratton (2006) because the authors provide a wealth of information that may address questions and challenges. Each tool described has its own assumptions, trade-offs, and benefits. Peterson and others (2007) summarize several tools that address application, spatial scale, analysis requirement, and data requirements, and link to other tools that we found to be useful. The authors also provide examples of site specific, small watershed, and large watershed projects in which they discuss appropriate tools for addressing particular decision needs.

We provide a short summary and web site for each of the models Peterson and others (2007) and Stratton (2006) identified, in addition to other models that have recently been developed. Tools are arranged based on their primary use, primary objective, and most current web site. These tools were identified in our manager interviews, synthesis documents, Joint Fire Sciences Program, and team knowledge on available tools. We identified every tool we could find, but this is not an exhaustive list. If we were unable to find a web site or access the tool, we did not list it. The list is organized in order in the following categories: Emissions, Fire and Technology Transfer Portals, Fire Behavior, Fire Effects, Fire Weather, Fuels Description, Fuels Planning, and Databases.

Emissions

BlueSky Smoke Forecast System (BlueSky): Modeling framework that links a variety of independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion. http://www.airfire.org/bluesky

Fire Emission Production Simulator (FEPS): Simulates fuel consumption, emission production, and plume buoyancy for prescribed burns and wildland fires under various meteorological conditions. http://www.fs.fed.us/pnw/fera/feps/

Consume 3.0: Predicts fuel consumption and pollutant emissions from wildland fires in all fuelbed types based on fuel loadings, weather conditions, site environmental data, and fuel moisture. Resource managers can determine when and where to conduct a prescribed burn to achieve desired objectives. http://www.fs.fed.us/pnw/fera/research/smoke/consume/index.shtml

Fire and Technology Transfer Portals

FIREHouse: Web-based project providing information about fire science and technology relevant to Washington, Oregon, Idaho, and Alaska. The portal provides one location for resource managers, decision-makers, scientists, students, and communities who want access to the results of efforts to understand and manage fire and fuels on public lands in these regions. http://depts.washington.edu/nwfire/

FRAMES: Web-based portal providing a systematic method of exchanging information and transferring technology among wildland fire researchers, managers, and other stakeholders in order to make wildland fire documents, data, tools, and other information resources easy to find, access, distribute, compare, and use. http://www.frames.gov/

Wildland Fire Air Quality Tools Portal: Provides a "one-stop shopping" portal for air quality tools. Designed to access the Wildland Fire Decision Support Systems. http://www.firesmoke.us/wfdss/

National Interagency Fuels, Fire, and Vegetation Technology (NIFTT): Provides land managers with science-based analysis tools and training focused on the assessment of fire behavior, fire effects, fire regimes, and vegetation dynamics. http://www.frames.gov/portal/server.pt/community/niftt/382/home/1626

Fire Behavior

BehavePlus: Predicts surface fire flame length, rate of spread, tree mortality, crown scorch height, spotting distance, and fire containment. Individual stand scale to 6th field HUCs. Not a data intensive tool but requires familiarity with fire behavior fuel models. BehavePlus equations are basic underlying equations used in FOFEM, FMA Plus, FFE-FVS, NEXUS, FARSITE, and FlamMap Supported by U.S. Forest Service Fire and Aviation Management. http://www.firemodels.org/index.php/national-systems/behaveplus

Fire Area Spread Simulator (FARSITE 4.0.4): Tests the potential effects of different fuel treatments on landscapes subjected to a fire or group of fires burning under given weather conditions. This is a fire growth simulation model that uses spatial information on topography and fuels along with weather and wind fields. Supported by U.S. Forest Service Fire and Aviation Management. http://www.firemodels.org/index.php/national-systems/farsite

FlamMap: Spatial fire behavior mapping and analysis program that requires a GIS layer of vegetation characteristics and fuel moisture and weather data. Unlike FARSITE, FlamMap makes independent fire behavior calculations (for example, fireline intensity and flame length) for each location of the raster landscape (cell), independent of one another. Supported by U.S. Forest Service Fire and Aviation Management. http://www.firemodels.org/index.php/national-systems/flammap

Fire Behavior Assessment Tool (FBAT): Design and prioritize hazardous fuel treatments and evaluate the effectiveness of proposed treatments in altering potential fire behavior. FBAT runs FlamMap in the background from an ArcMap platform while producing many of the same fire behavior characteristics that are output by FlamMap (such as flame length, fireline intensity, rate of spread, and fire type). The tool maps fire behavior metrics and maps each threshold, including only those polygons exceeding the threshold. Stand level tool. http://www.fire.org/index.php?option=com_content&task=view&id=143&Itemid=299

Fire Effects

Armillaria Response Tool (ART): Evaluates potential impacts of fuel treatments on Armillaria root disease. http://forest.moscowfsl.wsu.edu/fuels/art/

First Order Fire Effects Model (FOFEM): Predicts fuel consumption, soil heating, smoke production, and tree mortality caused by prescribed fire or wildfire. http://www.firelab.org/science-applications/fire-fuel/111-fofem

Wildlife Habitat Response Model (WHRM): Web-based tool to help fuel treatment planners evaluate the effects of fuel treatment alternatives on wildlife habitat elements. Developed by David Pilliod and Elena Velasquez. http://forest.moscowfsl.wsu.edu/fuels/whrm/whrm.html.

Combined Habitat Assessment Protocols (CHAP): Accounting tool and can generate an appraised habitat value for fish and wildlife when applied to a site or area. http://nwhi.org/inc/data/gisdata/hab/CHAP%20General%20Approach%20Version%2009-14-2011.pdf

Fire Weather

FireFamily Plus: Windows-based program that analyzes and summarizes an integrated database of fire weather and fire occurrence. Supported by U.S. Forest Service Fire and Aviation Management. http://www.firemodels.org/index.php/national-systems/firefamilyplus

WindNinja: Computer program that computes spatially varying wind fields for wildland fire application. http://www.firelab.org/research-projects/physical-fire/145-windninja

Fuels Description

Natural Fuels Photo Series: Helps land managers appraise fuel and vegetation conditions in natural settings. Includes 11 volumes representing various regions of the United States. There are 1 to 4 series in each volume, each having 4 to 17 sites. Sites include standard, wide-angle, and stereo-pair photographs. http://www.fs.fed.us/pnw/fera/research/fuels/photo_series/index.shtml

Fuel Characteristic Classification System (FCCS): Assigns fuel properties and fire potentials to landscapes at all scales across the United States. Consists of a large database of physical parameters that describe the abundance, physical character, and arrangement of wildland fuelbeds. http://www.fs.fed.us/pnw/fera/fccs/index.shtml

Fuels Planning

ArcFuels: Integrates a number of fire behavior models and corporate spatial data within a GIS framework. http://www.arcfuels.org/

Fire Regime Condition Class (FRCC): Interagency, standardized tool for determining the degree of departure from reference condition vegetation, fuels, and disturbance regimes. http://frames.nbii.gov/portal/server.pt/community/frcc/309/home/1397

Comparative Risk Assessment in Fire and Fuels Planning (CRAFT): Calculates relative risks and trade-offs associated with alternative fire and fuel management scenarios. Designed to lead natural resource managers through an integrated assessment of risks, uncertainties, and trade-offs that surround fire and fuel management. http://www.fs.fed.us/psw/topics/fire_science/craft/craft/

Most recently, Norman and others (2010) used a case study to illustrate the CRAFT planning process, which includes four stages: (1) objective setting and problem conceptualization, (2) alternative design, (3) probabilistic modeling of effects, and (4) synthesis. http://www.fs.fed.us/pnw/pubs/gtr802/Vol2/pnw_gtr802vol2_norman.pdf

Ecosystem Management Decision Support System (EMDS): Application framework for knowledge-based decision support of ecological assessments at any geographic scale. Integrates GIS with knowledge-based reasoning and decision support modeling technologies to provide decision support for a substantial portion of the adaptive management process. http://www.institute.redlands.edu/emds/manuscripts/docs/EMDS%20User%20Guide.pdf

Fire Effects Planning Framework (FEPF): Creates map libraries useful for identifying where and under what burning conditions fire may be beneficial for achieving fuel treatments with respect to fire behavior and effect upon other management objectives. http://leopold.wilderness.net/research/fprojects/F005.htm

Fire Effects Tradeoff Model (FETM): Simulates the effects of alternative land management practices on future landscape conditions over long periods and under diverse environmental conditions, natural fire regimes, and fuel and fire management strategies. http://www.fs.fed.us/r6/aq/fetm/index.htm

Rare Event Risk Assessment Process (RERAP): Estimates the risk that a fire will reach a particular point of concern before a fire-ending event occurs. Web site not located.

Simulating Patterns and Processes at Landscape Scales (SIMPPLLE): Watershed-level disturbance model designed as a management tool to improve understanding of how disturbance processes and vegetation interact to affect landscape change. http://www.fs.fed.us/rm/missoula/4151/SIMPPLLE/

Forest Inventory and Analysis Biomass Summarization System (FIA BioSum): Analysis framework that combines forest inventory data representing an analysis region, a treatment cost model, a fuel treatment effectiveness model, and a raw material hauling cost model to explore alternative landscape-scale treatment scenarios that achieve a variety of management objectives. http://www.fs.fed.us/pnw/fia/biosum/

Integrated Forest Resource Management System (INFORMS): Facilitates planning activities in the USDA Forest Service. Designed specifically to help support project-scale (NEPA) and landscape-scale planning. However, some users may find it useful for other types of planning exercises. http://www.fs.fed.us/informs/index.php

My Fuel Treatment Planner (MyFTP): Allows planners working at the level of a National Forest District, or similarly sized unit, to estimate costs, revenues, economic impacts, and surface fuels resulting from operations designed to reduce fuel loads in fire-prone forests. Software is limited in scope to the dry forests of the western United States. http://www.fs.fed.us/pnw/data/myftp/myftp.shtml

Fuels Management Analyst Plus (FMA Plus): Determines dead and down woody fuel loading by using either Brown's inventory methods or photo guides to assess crown fire risk and predict slash resulting from thinning and logging operations. Consists of three modules: (1) DDWoodyPC for estimating dead, downed woody fuel; (2) Photo Series Explorer to view scanned images of older photo guides to fuel loadings; and (3) CrownMass to predict crown fire risks and estimate slash loadings and Fuel Model Manager to create custom fuel models for use in CrownMass. http://www.fireps.com/fmanalyst3/index.htm

Vegetation Dynamics Development Tool (VDDT): Models the short- and long-term interactions of vegetation, management, and disturbance. Most analysts use it to depict vegetation as structure (e.g., grass/shrub, seedling, sapling, and pole) and cover (e.g., dominant species group) classes connected by growth, succession, management activities, and natural disturbances. Can be used for any system that connects state classes through probabilities of different kinds of changes. Is not spatial; produces a variety of database and graphical outputs, but not maps.

LANDIS and LANDIS-II: Models forest succession, disturbance (including fire, wind, harvesting, fuel treatments, insects, and climate change), and seed dispersal across large landscapes. LANDIS tracks age and spatial distribution of individual species and has a flexible spatial resolution. LANDIS-II also tracks living and dead biomass of species cohorts (using PnET-II).

Fire and Fuels Extension-Forest Vegetation Simulator (FFE-FVS): Stand-level model provides forest managers with a method for assessing the effects of treatment alternatives on fuel dynamics and fire potential into the future.

Fireshed Assessment: Integrated approach to landscape planning. "Firesheds" are large (thousands of acres) landscapes delineated based on fire regime, condition class, fire history, fire hazard and risk, and potential wildland fire behavior. Fireshed assessment is an interdisciplinary and collaborative process for designing and scheduling site-specific projects consistent with the goals of the Healthy Forests Restoration Act, National Fire Plan, and National Forest land and resource management plans (Ager 2006). http://www.treesearch.fs.fed.us/pubs/25943

Optimizing Fuel Solutions and Ecological Values in Landscapes (FUELSOLVE): Planning fuel treatment and vegetation management with fuel treatment projects and forest planning efforts (e.g., scenario planning, prioritization, describing desired future conditions, and fire effects modeling).

Smoke Impact Spreadsheet (SIS): Planning model for calculating particulate matter emissions and concentrations downwind of wildland fires. Conservatively predicts downwind particulate matter concentrations for comparison with appropriate Federal or state air quality standards. http://www.airsci.com/SISmodel/SIS_Users_Manual-6.17.03.pdf131

Tool for Exploratory Landscape Scenario Analysis (TELSA): Spatially explicit state and transition model that can be used to model the short- and long-term interactions of vegetation, management, and disturbance. Most analysts use it to depict vegetation as structure (e.g., grass/shrub, seedling, sapling, and pole) and cover (e.g., dominant species group) classes connected by growth, succession, management activities, and natural disturbances.

The Interagency Fuels Treatment Decision Support System (IFT-DSS): Provides a user interface for the applications of a combination of models that are currently under development (JFSP 2009).

Quick-Silver: Economic analysis tool for long-term and on-the-ground resource management projects. Provides a cost/benefit framework to evaluate different management scenarios.

Databases

National Fuel Moisture Database (NFMD): Web-based system that enables users to view sampled and measured live- and dead-fuel moisture information. Routinely updated by fuels specialists who monitor, sample, and calculate fuel moisture data. Provides a repository for sampled live- and dead-fuel moisture and a resource for anyone interested in obtaining fuel moisture data. Designed to be used in land management. Extent and details of available fuel moisture data varies by state, site, and measurement frequency; thus, there is considerable inconsistency. http://72.32.186.224/nfmd/public/index.php

Fire Effects Information System (FEIS): Provides background information on the potential effects of fire on flora and fauna. Summarizes the flora and fauna biology, ecology, and relationships to fire. http://www.fs.fed.us/database/feis/

Glossary of Wildland Fire Terminology (2011): http://www.nwcg.gov/pms/pubs/glossary/m.htm

Wildland Fire Lessons Learned Center: Provides cutting-edge knowledge to enhance and sustain safe and effective work practices in the wildland fire community using past and present lessons. http://www.wildfirelessons.net/

NOAA Paleoclimatology Fire History Data Sets: International Multiproxy Paleofire Database (IMPD) is an archive that contains fire history data derived from tree scars and charcoal in sediment records. Designed to be a permanent repository for high-quality paleofire records from around the world. Search engine functions by the contributor of the data or by state. For Idaho, Oregon, Washington, Utah, and Montana there were 122 different data sets. http://www.ncdc.noaa.gov/paleo/impd/paleofire.html

Forest Inventory and Analysis (FIA): Nationwide database from permanent plots on a grid. Allows users to generate tables and maps of forest statistics through a web browser without having to understand the underlying data structures. Also enables users to run any of the standard reports for a specific area of interest and survey year or create completely customized reports based on user-specified criteria. Saves work to a hard drive to load/re-run custom retrievals. (Data from FIA were used in Chapters 5 and 11.) http://apps.fs.fed.us/fido/

Appendix C: Chapter 11 Supplements

Evaluating Silvicultural Treatment Scenarios Using Forest Inventory and Analysis

This appendix summarizes the pre- and post-treatment forest and fire characteristics represented as frequency histograms, and compares characteristics of treatable forests with all forests. Up to six treatments were evaluated for each condition (stand), including crown thinning, thinning from below, and restoration treatments. A rule-based scenario, Any:ptorch, was used to select the best treatment for each condition based on the amount by which hazard score could be reduced. When there were ties among treatments, reduction in the probability of torching and net revenue were used to select the best one. Conditions with an initial hazard score of zero (no hazard with respect to probability of torching, torching index, surface flame height, and mortality volume percent) were not included in the set of treated conditions because they were already low hazard by definition. Those with no reduction in hazard score under any treatment were omitted from the set of treated conditions because no modeled treatment was deemed effective.

The histogram summaries are organized by region: Northern California and Klamath, Pacific Northwest Interior, Northern and Central Rocky Mountains, and Utah. For each region, we present five kinds of summaries of treatment results under the Any: Ptorch scenario for up to three forest type groups with sufficient numbers of treatable conditions (at least 10) in the region to generate a viable histogram output (Douglas-fir and True Fir, Pine and Western Larch, and Other).

The five summaries are:

1. All versus Treatable—a comparison of all conditions versus the conditions that were treatable. The forest characteristics show a comparison of quadratic mean diameter, trees per acre, canopy cover, and hazard score for all forests in that species group versus the forests for which one or more of our modeled silvicultural treatments were estimated to be effective.
2. Composite Hazard Score—a comparison of hazard score before and after treatment using the most effective treatment, only for forests where effective treatment was possible.
3. Stand structure metrics—a comparison of the stand metrics quadratic mean diameter, trees per acre, basal area, and FFE-FVS-estimated canopy cover before and after treatment using the most effective treatment, only for forests where effective treatment was possible.
4. Fire hazard metrics—a comparison of the hazard metrics Ptorch, surface flame length, torching index, and mortality volume percent, before and after treatment using the most effective treatment, only for forests where effective treatment was possible
5. Economic implications—on-site treatment cost, net revenue, value at the mill-gate and volume of merchantable wood extracted, value at the mill-gate and weight of energy wood extracted, percent of all costs represented by the transportation of energy wood, and percent of total revenues accounted for by sales of energy wood.

These histograms, organized in most cases as one region-forest type group combination and multiple attributes per page, describe the unreserved forest landscape and treated acres under the Any:Ptorch scenario by reporting the proportion of forested area (on the Y-axis) at each attribute level (on the X-axis). The areal proportions can be easily translated into acres, if desired, by multiplying the proportions by the area, in acres, printed in the text block included in each histogram.

As a point of reference, each histogram also contains the mean and a roughly calculated sampling error[1] (SE) for one attribute in one region/forest type group combination. Sampling errors tend to be smaller as area represented (and the associated sample size) increases. The true (population) mean has a 95 percent chance of being contained by the interval constructed as the sample mean +/- two times the SE. In some cases, the X-axis of the histogram is truncated and the last histogram bar on the X-axis represents a larger range than the other histogram bars; the last X-axis label is modified accordingly. Note that histograms are only plotted for cases where there are at least 10 conditions for a region/forest type group combination. It is inadvisable to attempt inferences from fewer than 10 conditions, and some analysts are more comfortable with a sample size minimum of 30.

To stimulate interest in and understanding of this extensive statistical data resource, we offer interpretation of each histogram for the Douglas-fir and True Fir forest type group in the Northern California and Klamath region. Interpretations for other regions and forest type groups will differ, but we hope that the highlights provided for this region and forest type group will inspire curiosity and serve as examples of how to extract useful information from the data summaries.

All Versus Treatable

From a total of 1.1 million acres of Douglas/grand fir types in the Northern California and Klamath region, only 32 percent of the area (368,000 acres) could be effectively treated by one or more of the six modeled silvicultural treatments. By definition, a condition considered for treatment must be initially hazardous; thus those conditions that didn't rate as hazardous (as shown in the 0 bar of the Hazard Score histogram at the bottom of the page) were untreatable, as were those where no treatment achieved a reduction in hazard score—the number of ways that a condition would rate as hazardous (with respect to probability of torching >20 percent, torching index <20 mph, surface flame height >4 ft, and mortality volume >30 percent of total volume). Hazard score is calculated as the number of hazard thresholds exceeded on a condition. The treatable acres were approximately evenly distributed among the four hazard scores. The conditions that were deemed treatable roughly reflect the all stands distribution of quadratic mean diameter and trees per acre, but treatable conditions had significantly greater canopy cover, typically 40 to 100 percent.

Composite Hazard Score

By definition, a condition considered for treatment must be initially hazardous (no pre-treatment condition has a hazard score of zero), and since treatment was considered effective only if hazard score was reduced by at least one point, no post-treatment

[1] These sampling errors do not account for the different landscape weights (acre expansion factors) associated with each forested condition; given that conditions that are smaller than a full plot tend to have greater variability and that their contribution to SE is not scaled down accordingly, calculated SE somewhat overstates true SE. It is important to note that SE does not reflect any error or uncertainty associated with models used to generate estimates of, for example, volume or surface flame height.

condition has a hazard score >3. In these forests, mean hazard score dropped from 2.5 to 0.8, and the acres rated as hazardous by three or four criteria dropped from about 40 percent of the treatable acres to less than 7 percent. Impressively, compared to other forest types and regions, hazard score was reduced to zero on over 40 percent of the effectively treatable area and was reduced to 1 on another 40 percent.

Stand Structure Metrics

The best treatment for each condition achieved an average 50 percent reduction in tree density and a net increase in QMD by virtue of removing more small than large trees. For this reason, and the fact that most of the basal area could be found in larger trees, reduction in basal area was not as dramatic as reduction in tree density but was significant nevertheless, as evidenced by a 58 ft^2 drop in the mean with a SE on the order of 10. Canopy cover was also reduced significantly (by 20 percent cover on average). This highlights the importance of looking at both the histogram and the mean and SE statistics, as shifts in frequency distributions that maintain an approximately constant shape can be hard to detect visually.

Fire Hazard Metrics

Fuel treatment changed the potential fire characteristics from the pre-treatment conditions, illustrating that these generic prescriptions would influence the fire characteristics in these forests. The probability of torching dropped from a mean value of 53 to 12; many sites (more than half) had a pre-treatment probability of greater than 50 percent, but following treatment, nearly 80 percent of sites had less than 10 percent probability of torching. Incidence of low torching index (high torching hazard) was significantly reduced. Treatment had little impact on mean surface flame length, but there was a notable uptick in the frequency with which it was below our target of 4 ft. The impact on mortality volume was perhaps most impressive. Not only did the mean value drop from 76 to 26 percent, in 20 percent of the cases, post-treatment mortality was predicted at >30 percent, whereas close to 80 percent of pre-treatment acres had >30 percent mortality volume.

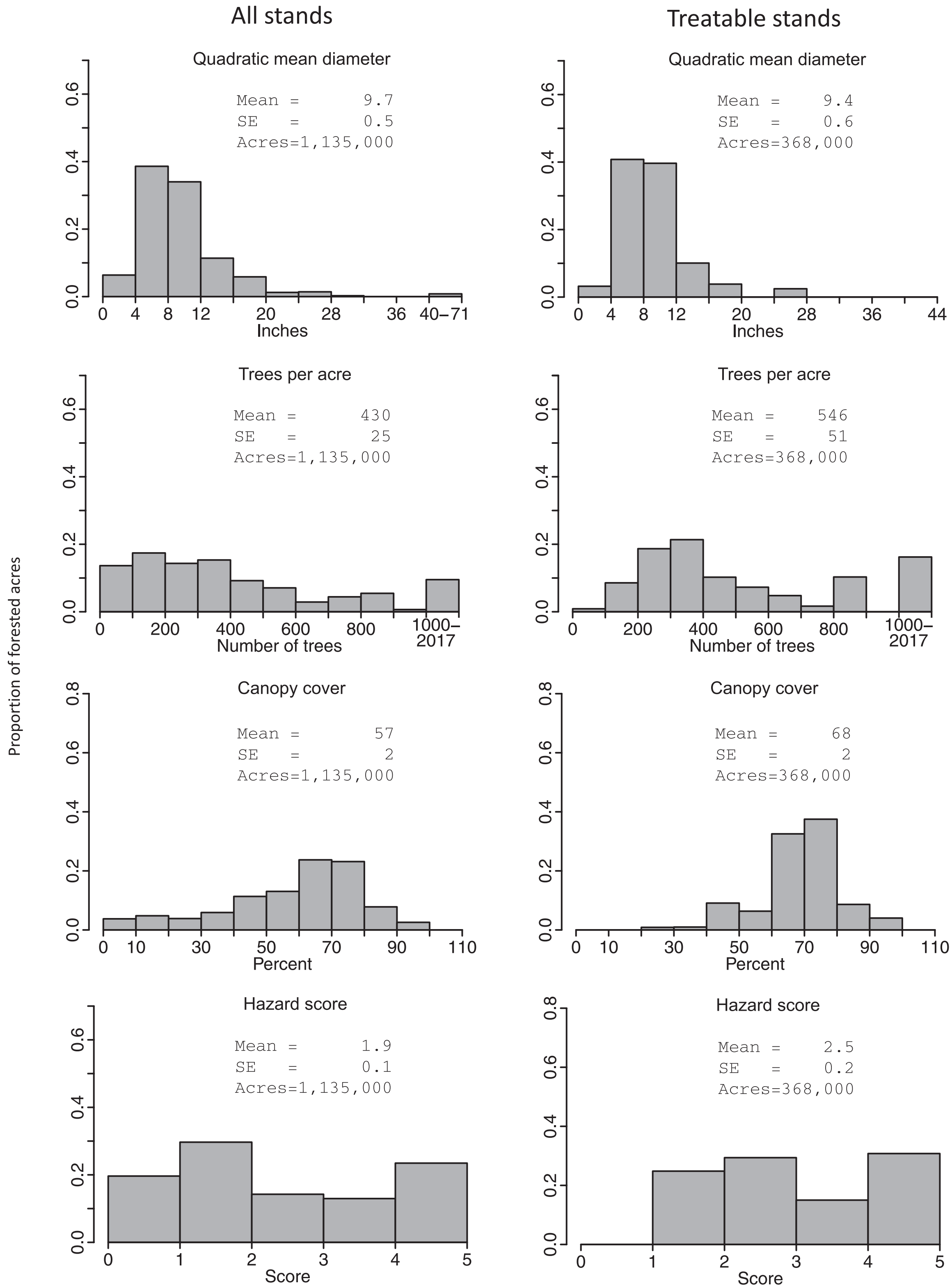
Economic Implications

On-site treatment cost per acre is highly variable, depending, for example on tree size, number of trees harvested, slope, stand density, distance to road, and is skewed with a long tail because some acres are very expensive to treat. The high mean ($1616/acre) reflects this skew, while the median is $1225/acre and the mode is between $500 and $750/acre. However, sales of products and energy associated with the prescriptions modeled for these conditions make net revenue a more relevant attribute to consider. This varies from a net cost of more than $2000 (negative net revenue) to a positive net revenue of over $9400/acre. In this case, the skew generates a long tail toward high net revenues as the conditions that cost the most to treat (have the most material to remove) also have the most material to sell. Whether or not high volume conditions would realistically be available for treatment is an open question, but it is encouraging that the median net revenue is positive ($244/acre), suggesting that in most cases, treatment revenues can cover treatment costs. The value of merchantable wood extracted in these treatments is skewed with a long tail and varies from $0 to nearly $10,000 per acre, with a quarter of the area capable of generating in excess of $4000/acre of merchantable wood and another quarter capable of generating less than one-tenth that value. The distribution of merchantable volume is similarly bi-modal, with 30 percent of the treatable area generating less than 250 ft^3/acre and another 30 percent generating in excess of 2500 ft^3/acre.

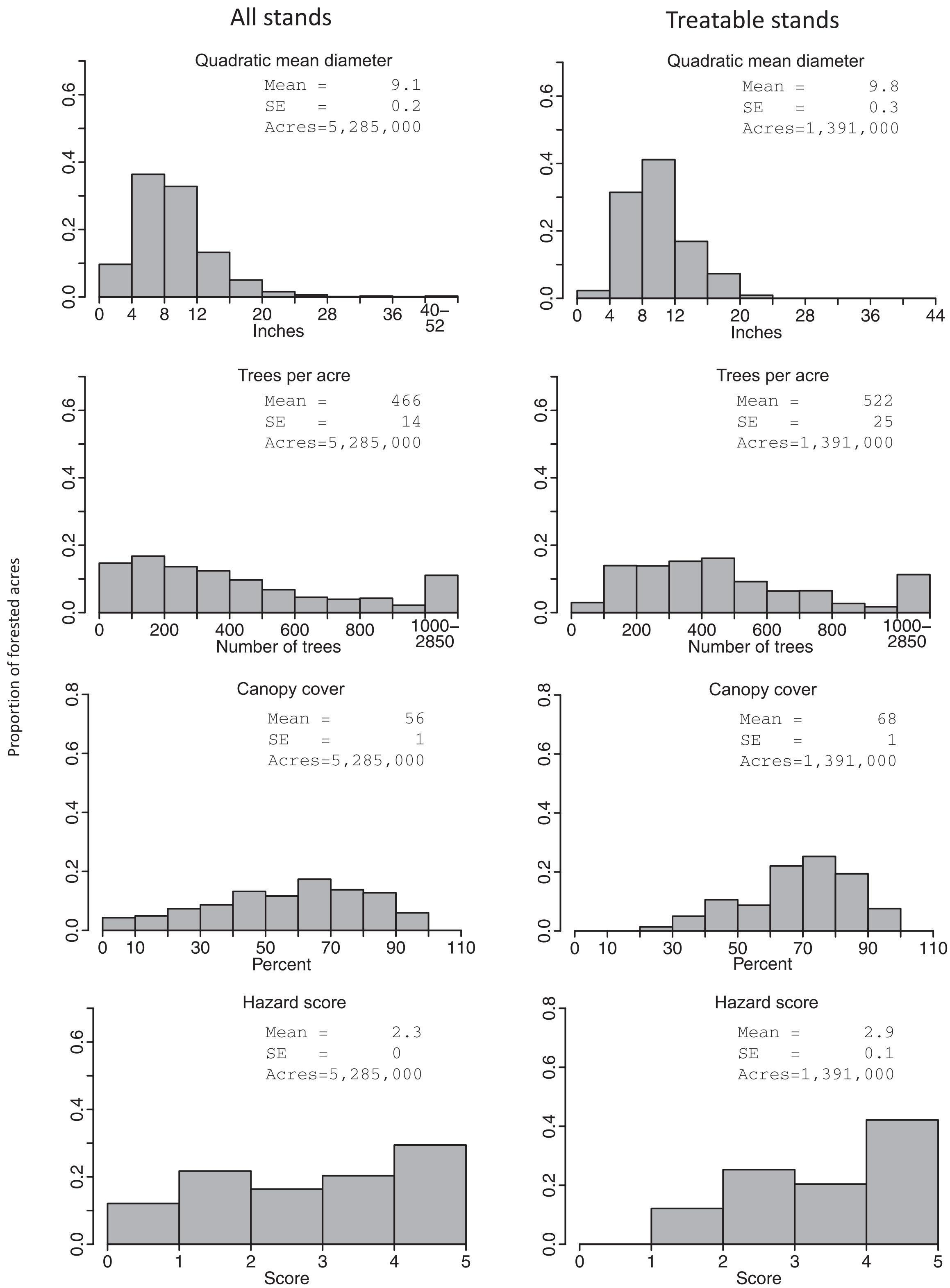
Similar patterns persist for energy wood, though the dollar amounts per acre are far less than for merchantable wood, and nearly half of the area generates less than 10 green tons/acre of energy wood. When considering the total costs of treatments (include costs for on site and transportation associated with what is extracted), the transportation costs for delivering energy wood to bioenergy facilities is comparatively small, averaging 4 percent of total costs; however, considering how much of the harvest value is in energy wood and that on-site costs are generally the greatest share of costs, these transportation costs are not insignificant and, in some scenarios, may preclude recovery of energy wood from treated conditions. On average, 37 percent of the value of materials sold in association with these treatments is generated by sales of energy wood, though a portion of the merchantable wood that is transported to and processed at lumber and plywood mills (i.e., mill residues not utilized for manufactured wood or paper products) will also be used for energy. The average percent value is skewed by the nearly 20 percent of the area where no merchantable wood is recovered due to either tree size or an abundance of non-commercial species such that total sales are much less than for areas where energy wood is a smaller proportion of the mix. In any case, treatment costs would rarely be covered without the revenue obtained from sales of merchantable wood.

All Versus Treatable

Northern California and Klamath - Douglas-fir and True fir

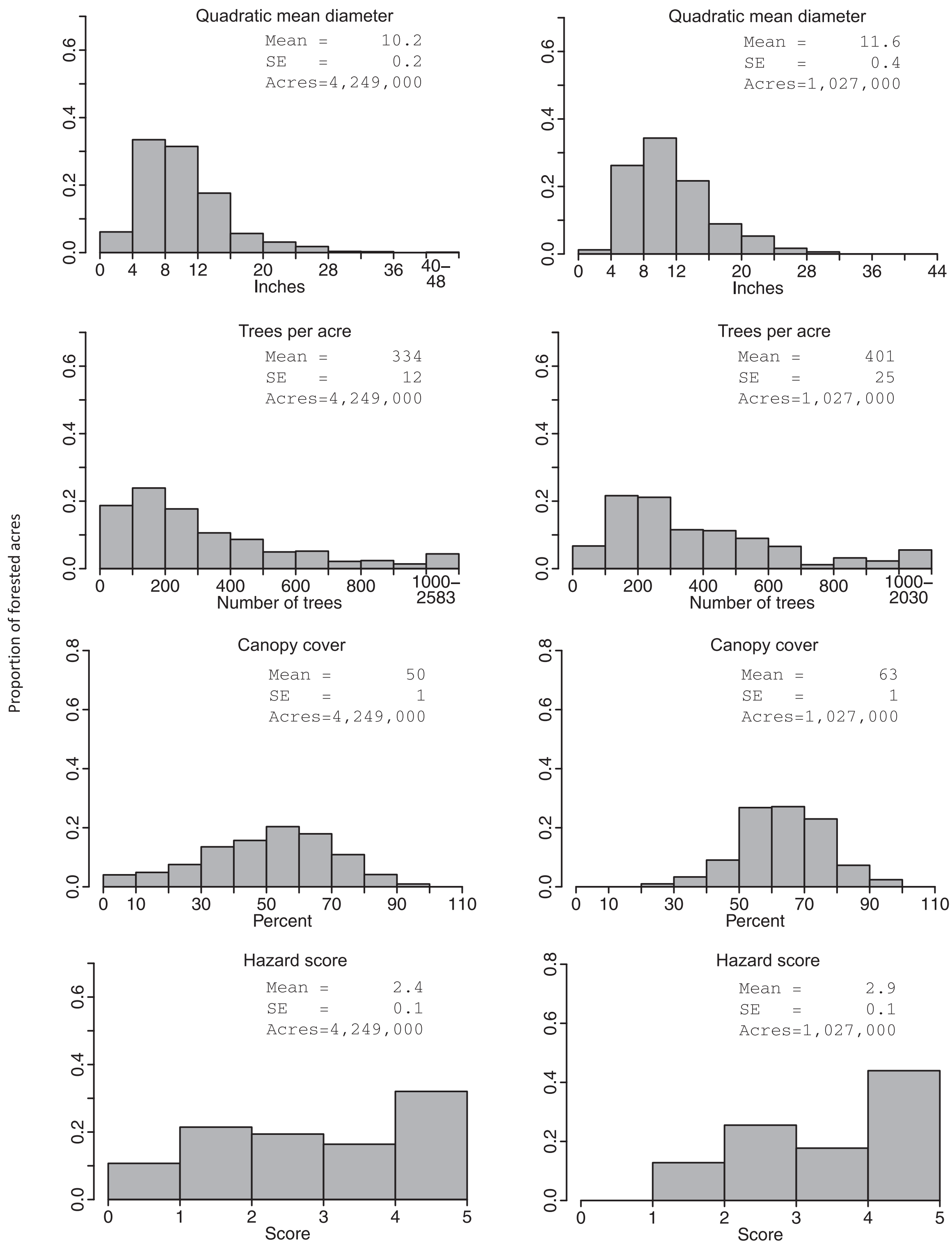


Northern California and Klamath - Other Species



Pacific Northwest Interior - Douglas-fir and True Fir

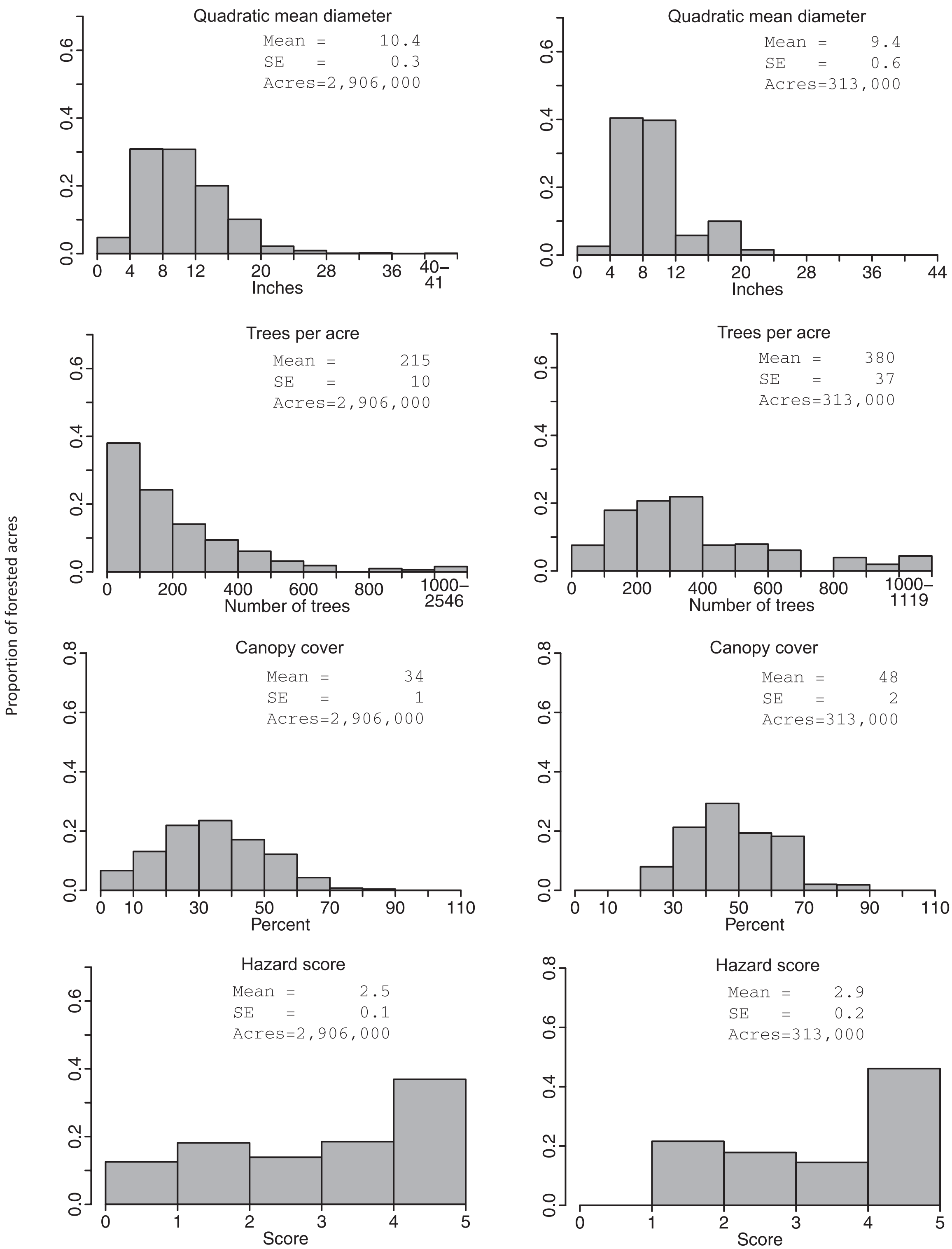
All stands | Treatable stands



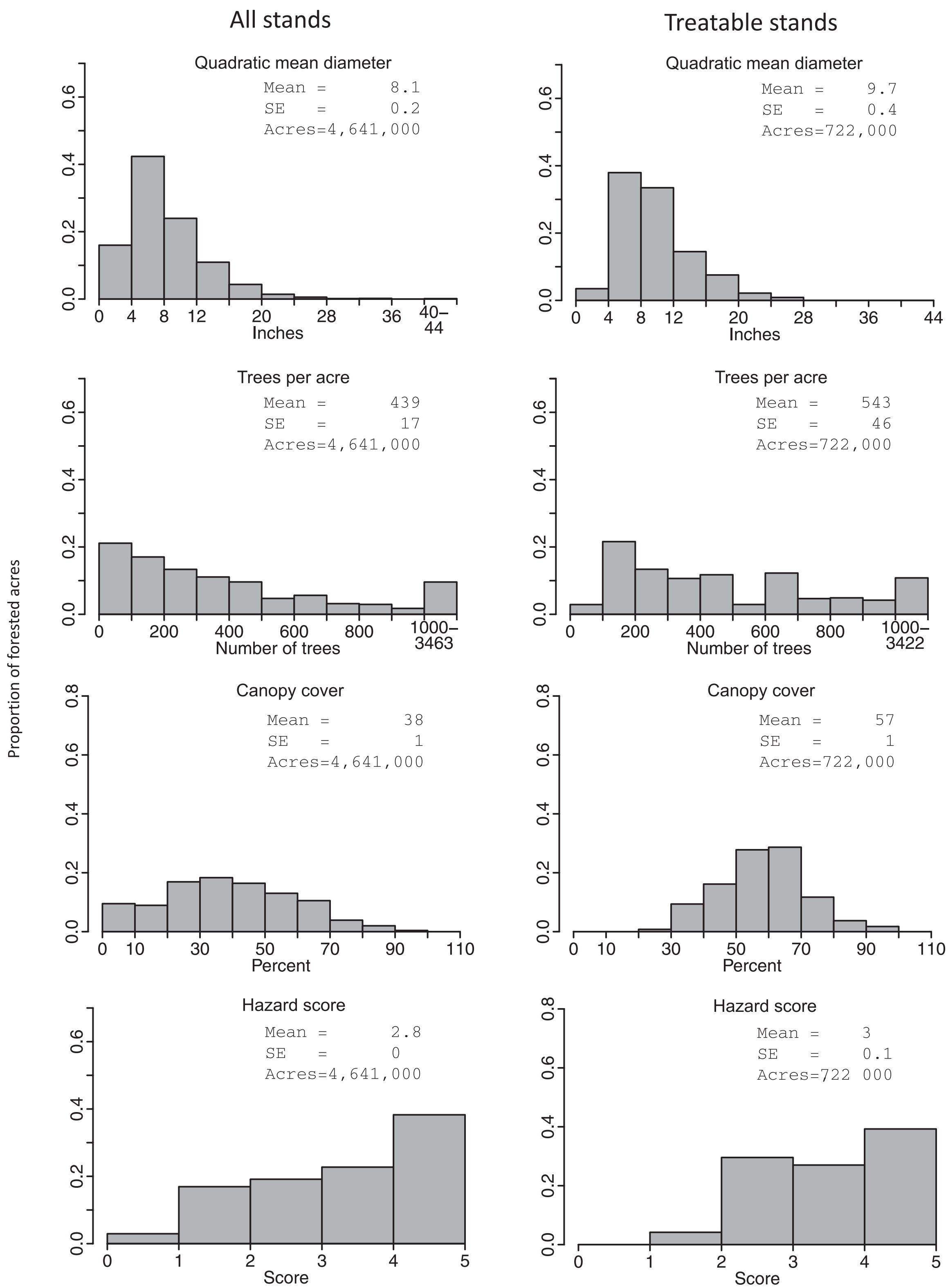
Pacific Northwest Interior - Pine and Western Larch

All stands

Treatable stands

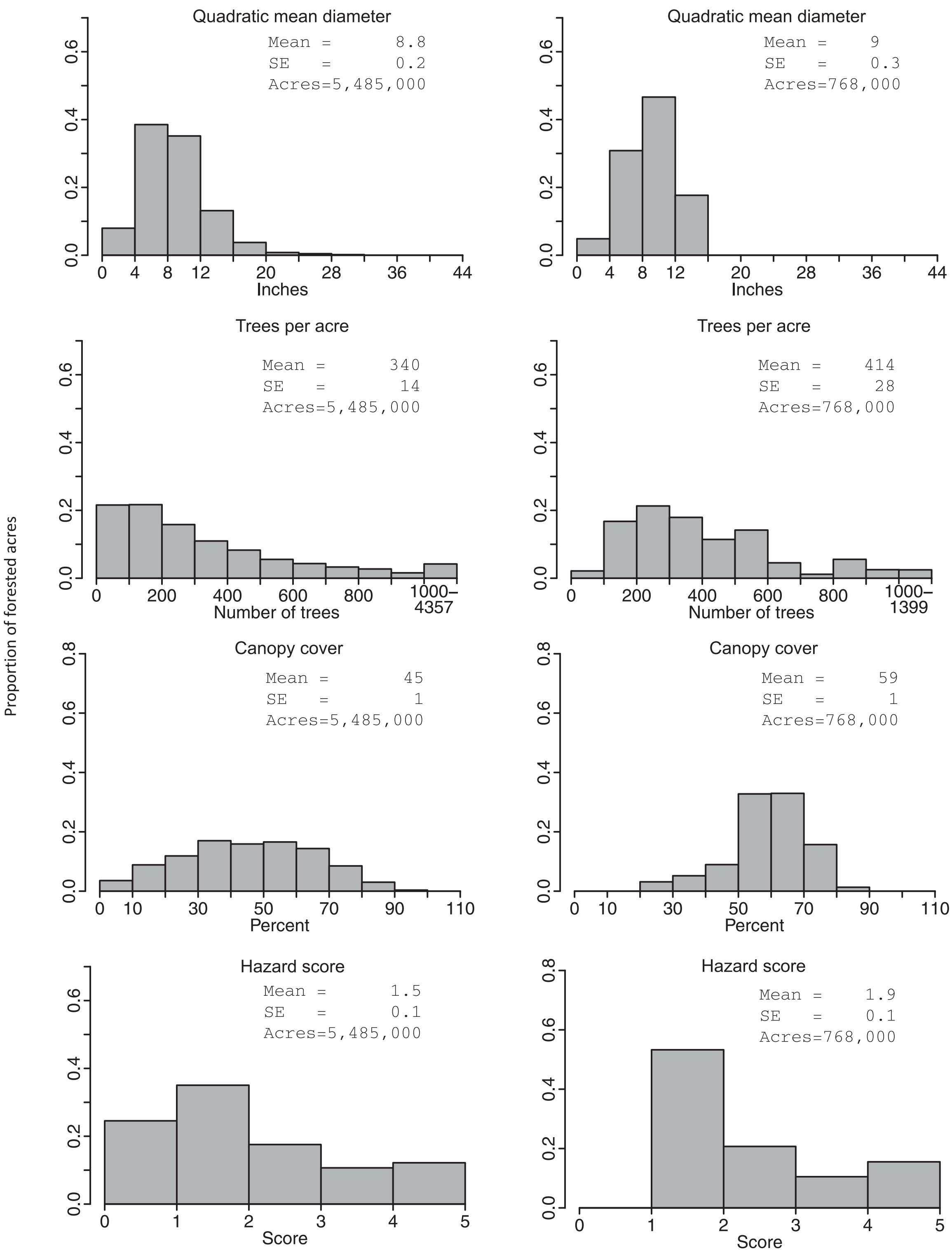


Pacific Northwest Interior - Other Species

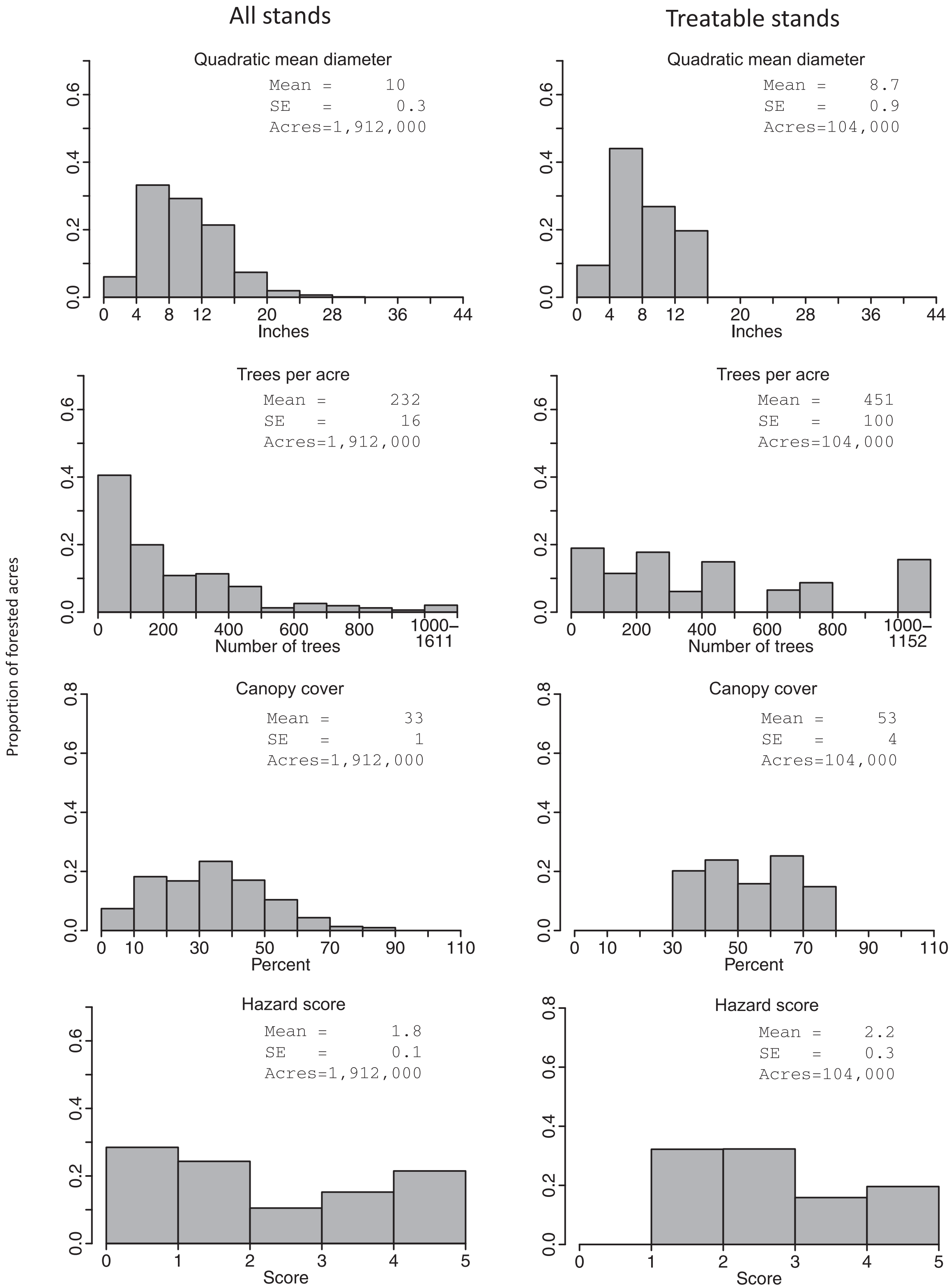


North and Central Rocky Mountains - Douglas-fir and True Fir

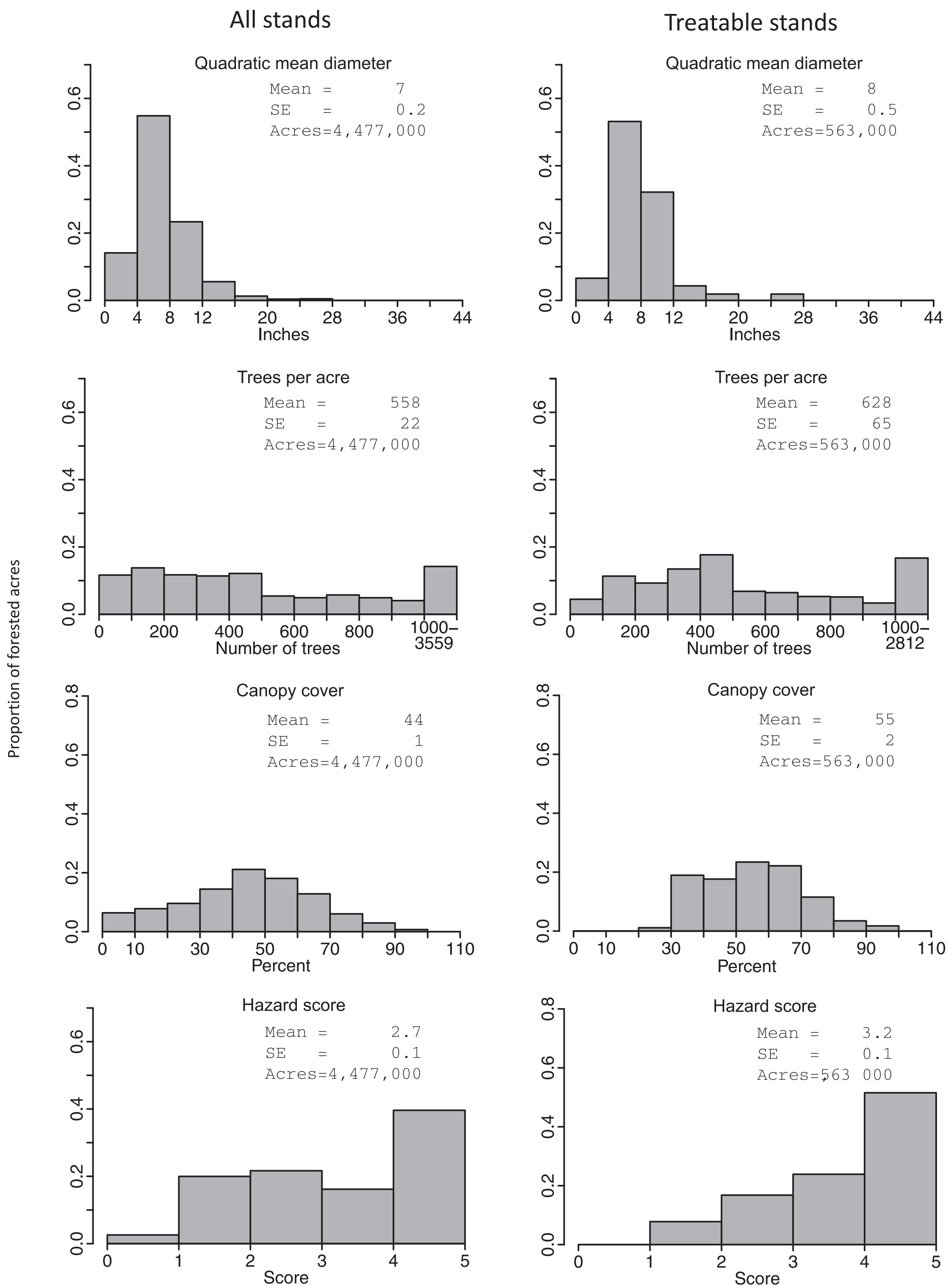
All stands | Treatable stands

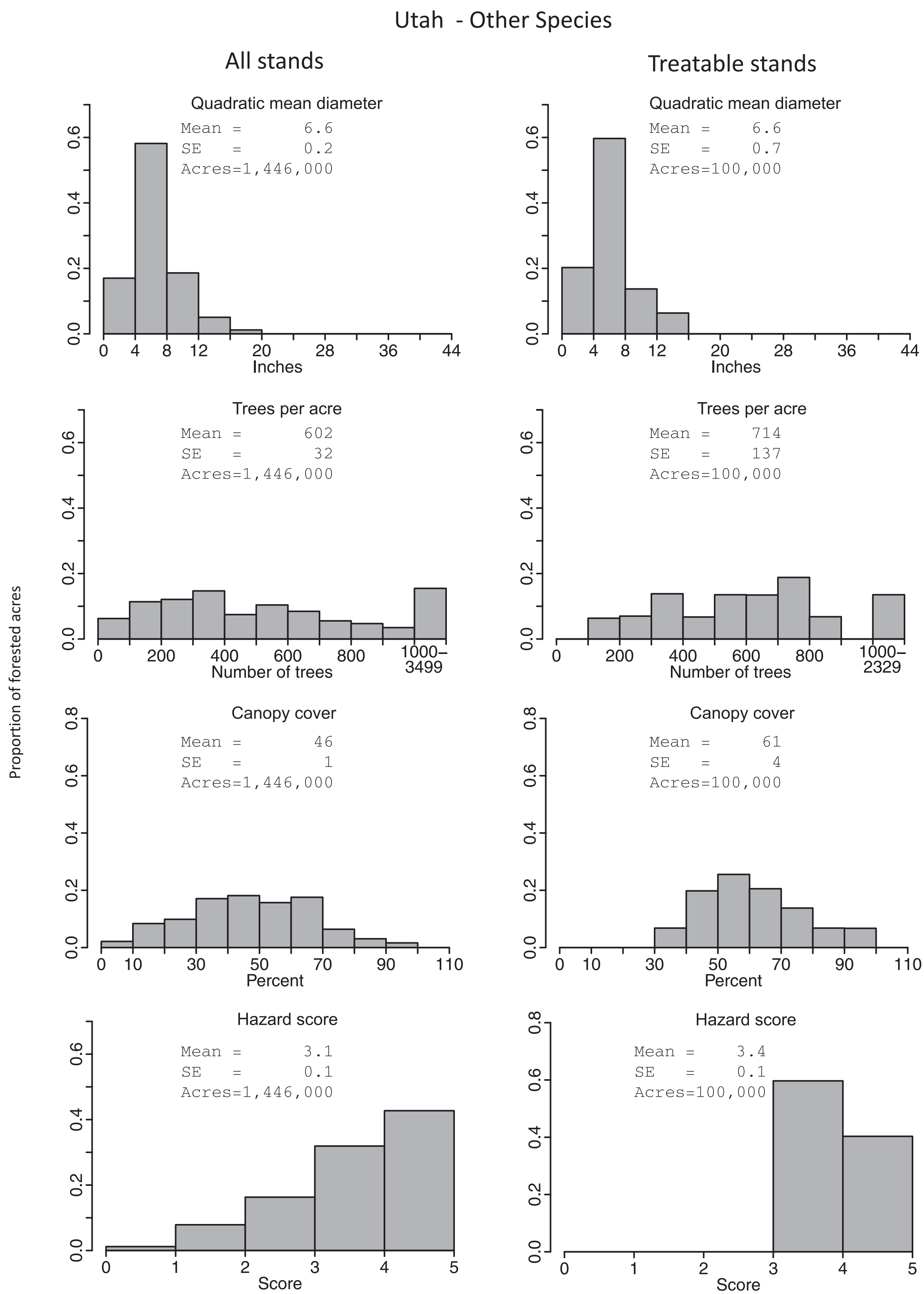


North and Central Rocky Mountains - Pine and Western Larch

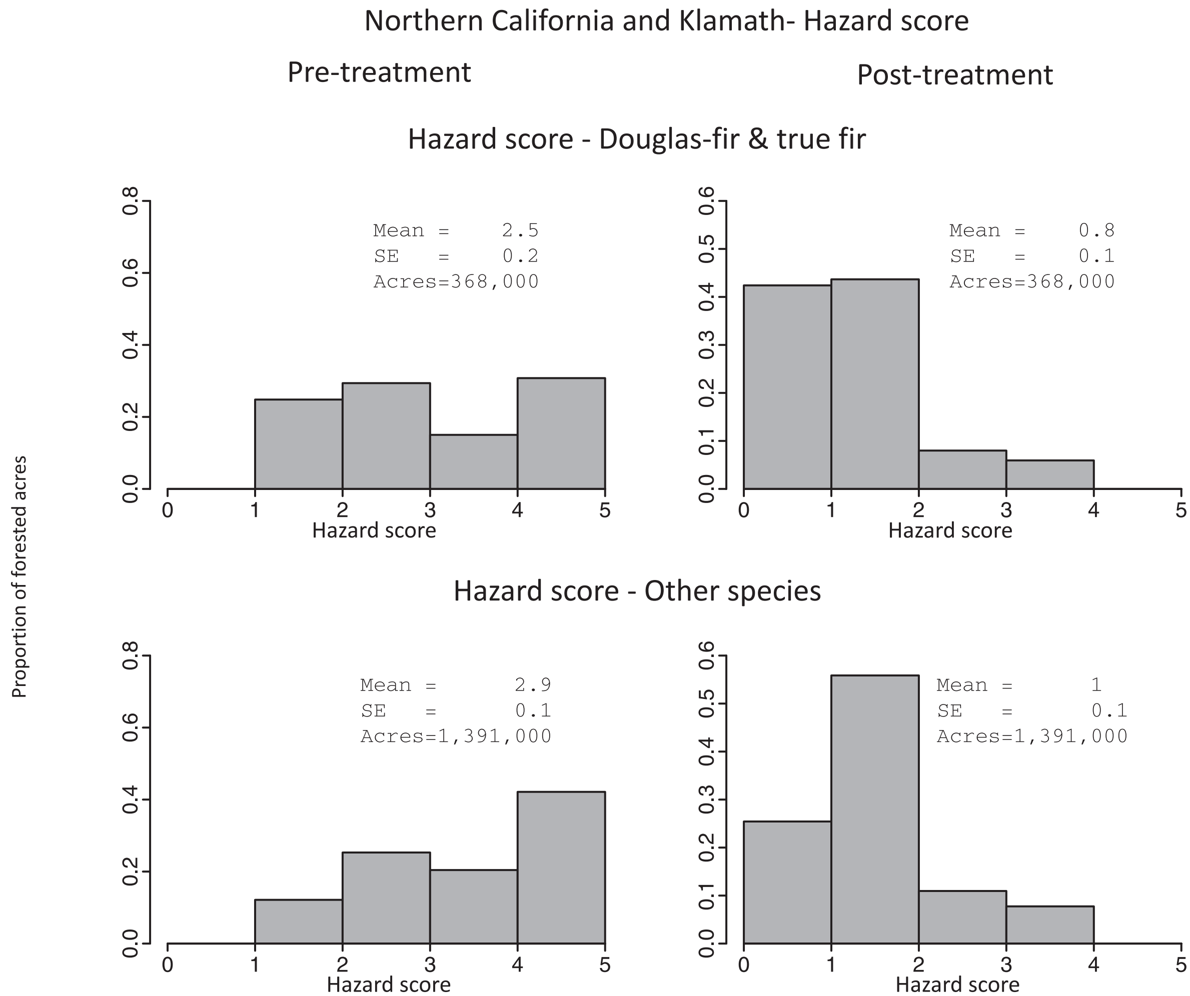


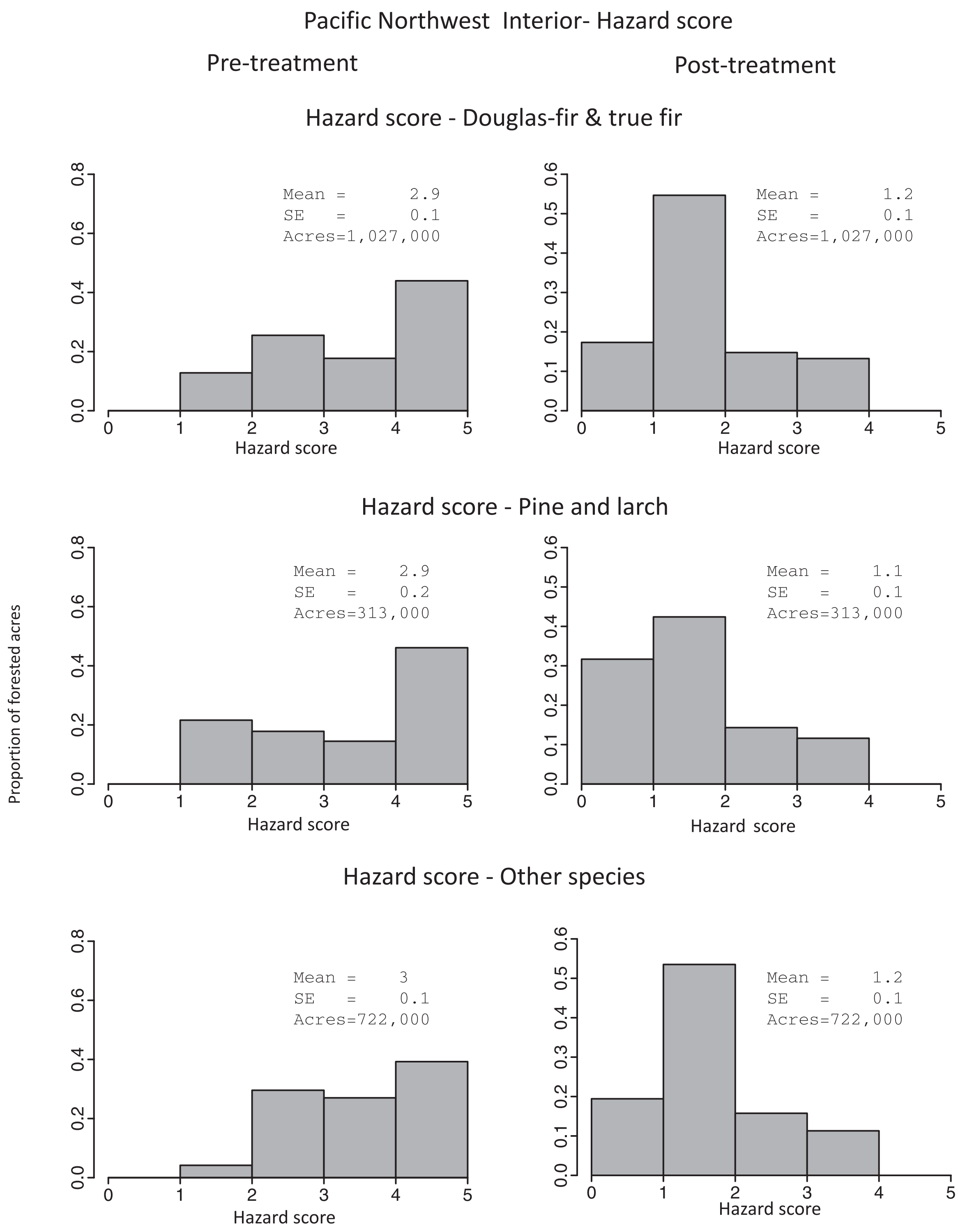
North and Central Rocky Mountains - Other Species

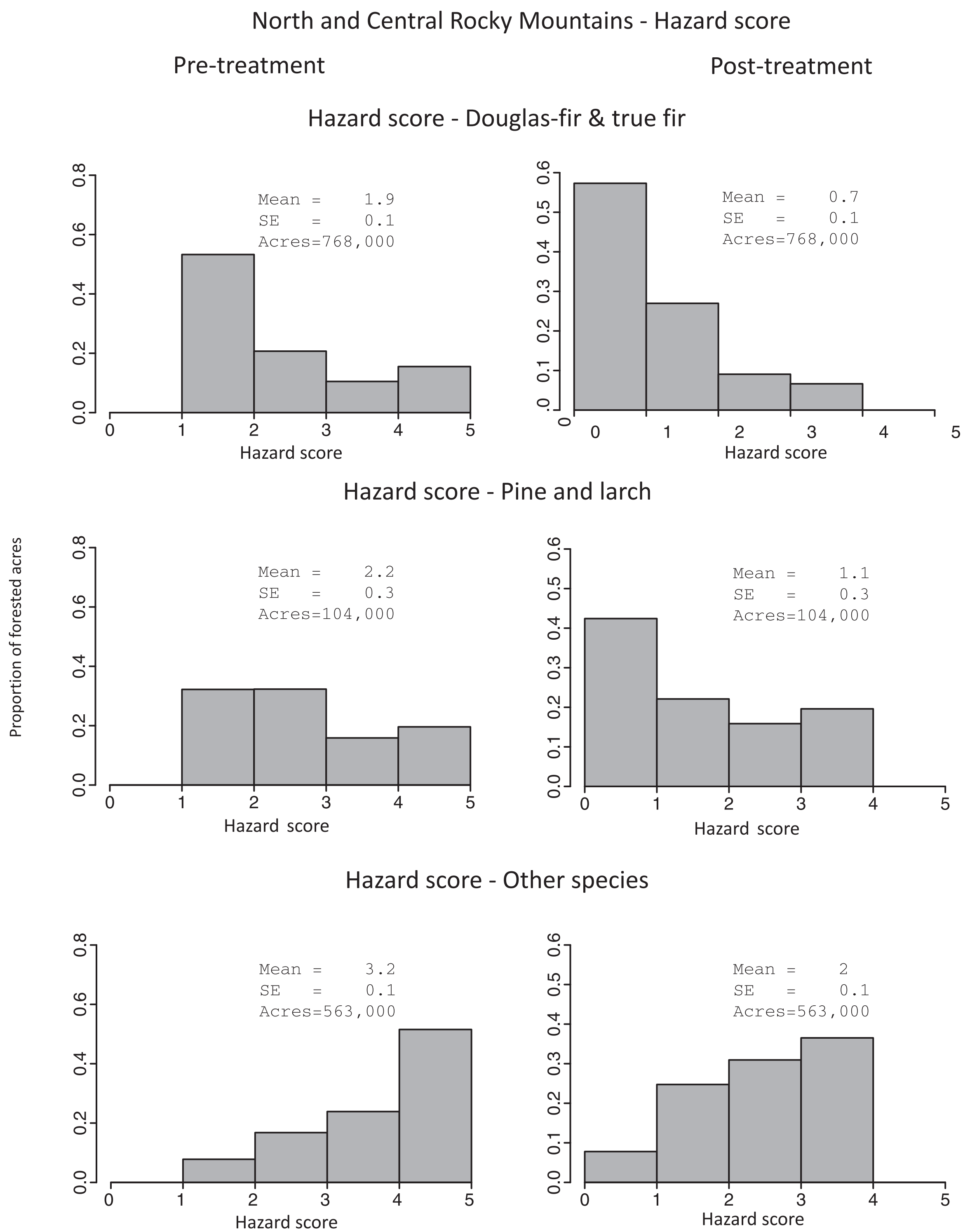



Utah - Other Species
All stands
Treatable stands
Proportion of forested acres
Quadratic mean diameter
Mean = 6.6
SE = 0.2
Acres=1,446,000
Inches
Quadratic mean diameter
Mean = 6.6
SE = 0.7
Acres=100,000
Inches
Trees per acre
Mean = 602
SE = 32
Acres=1,446,000
Number of trees
1000–3499
Trees per acre
Mean = 714
SE = 137
Acres=100,000
Number of trees
1000–2329
Canopy cover
Mean = 46
SE = 1
Acres=1,446,000
Percent
Canopy cover
Mean = 61
SE = 4
Acres=100,000
Percent
Hazard score
Mean = 3.1
SE = 0.1
Acres=1,446,000
Score
Hazard score
Mean = 3.4
SE = 0.1
Acres=100,000
Score

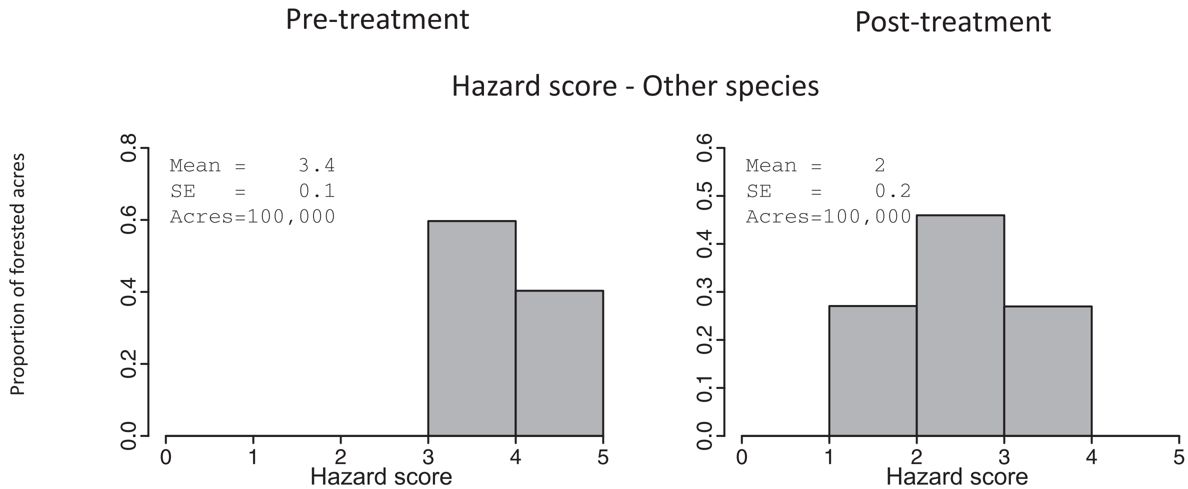
Hazard Score


Northern California and Klamath- Hazard score
Pre-treatment
Post-treatment
Hazard score - Douglas-fir & true fir
Mean = 2.5
SE = 0.2
Acres=368,000
Mean = 0.8
SE = 0.1
Acres=368,000
Hazard score
Hazard score
Hazard score - Other species
Mean = 2.9
SE = 0.1
Acres=1,391,000
Mean = 1
SE = 0.1
Acres=1,391,000
Hazard score
Hazard score
Proportion of forested acres

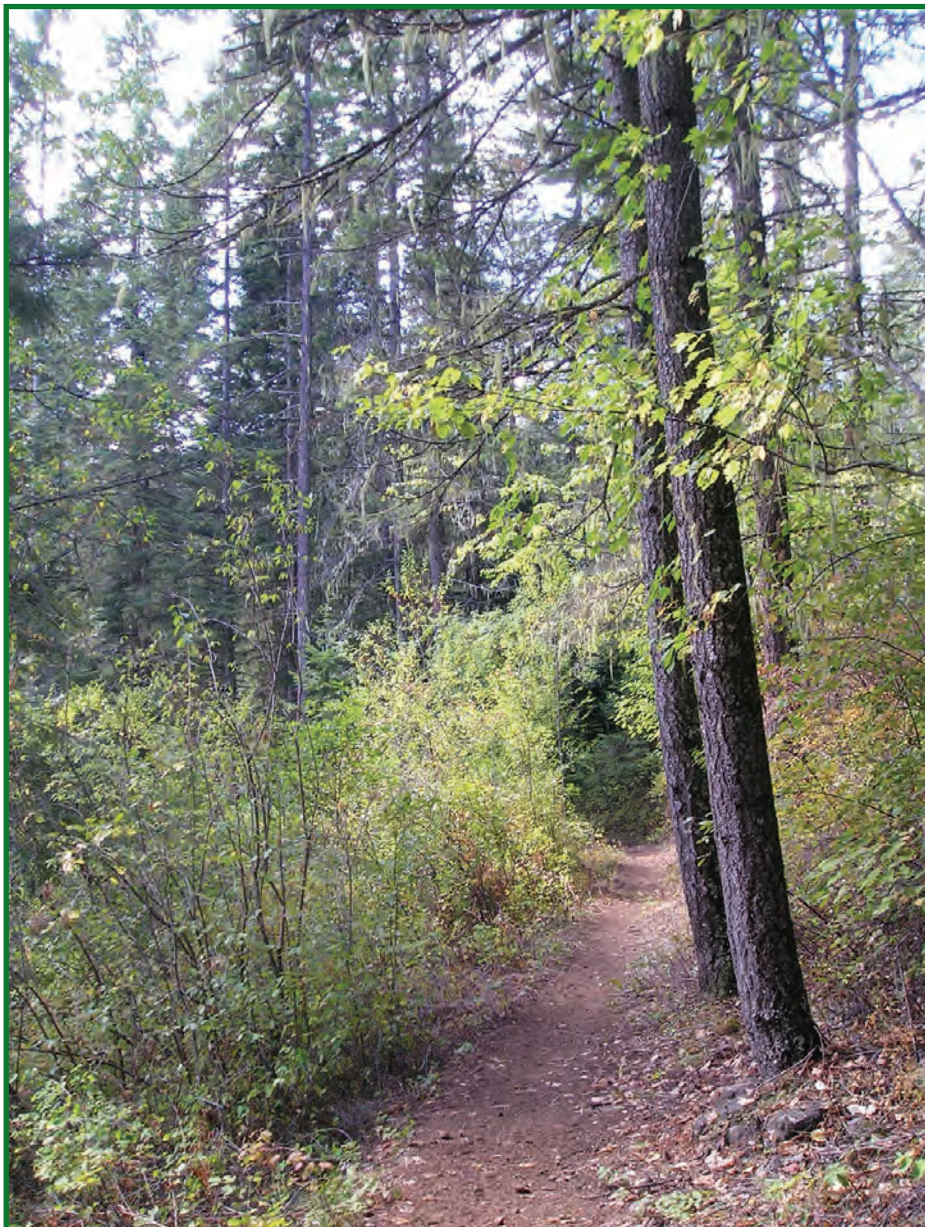

Pacific Northwest Interior- Hazard score
Pre-treatment
Post-treatment
Hazard score - Douglas-fir & true fir
Mean = 2.9
SE = 0.1
Acres=1,027,000
Mean = 1.2
SE = 0.1
Acres=1,027,000
Hazard score
Hazard score
Hazard score - Pine and larch
Mean = 2.9
SE = 0.2
Acres=313,000
Mean = 1.1
SE = 0.1
Acres=313,000
Proportion of forested acres
Hazard score
Hazard score
Hazard score - Other species
Mean = 3
SE = 0.1
Acres=722,000
Mean = 1.2
SE = 0.1
Acres=722,000
Hazard score
Hazard score

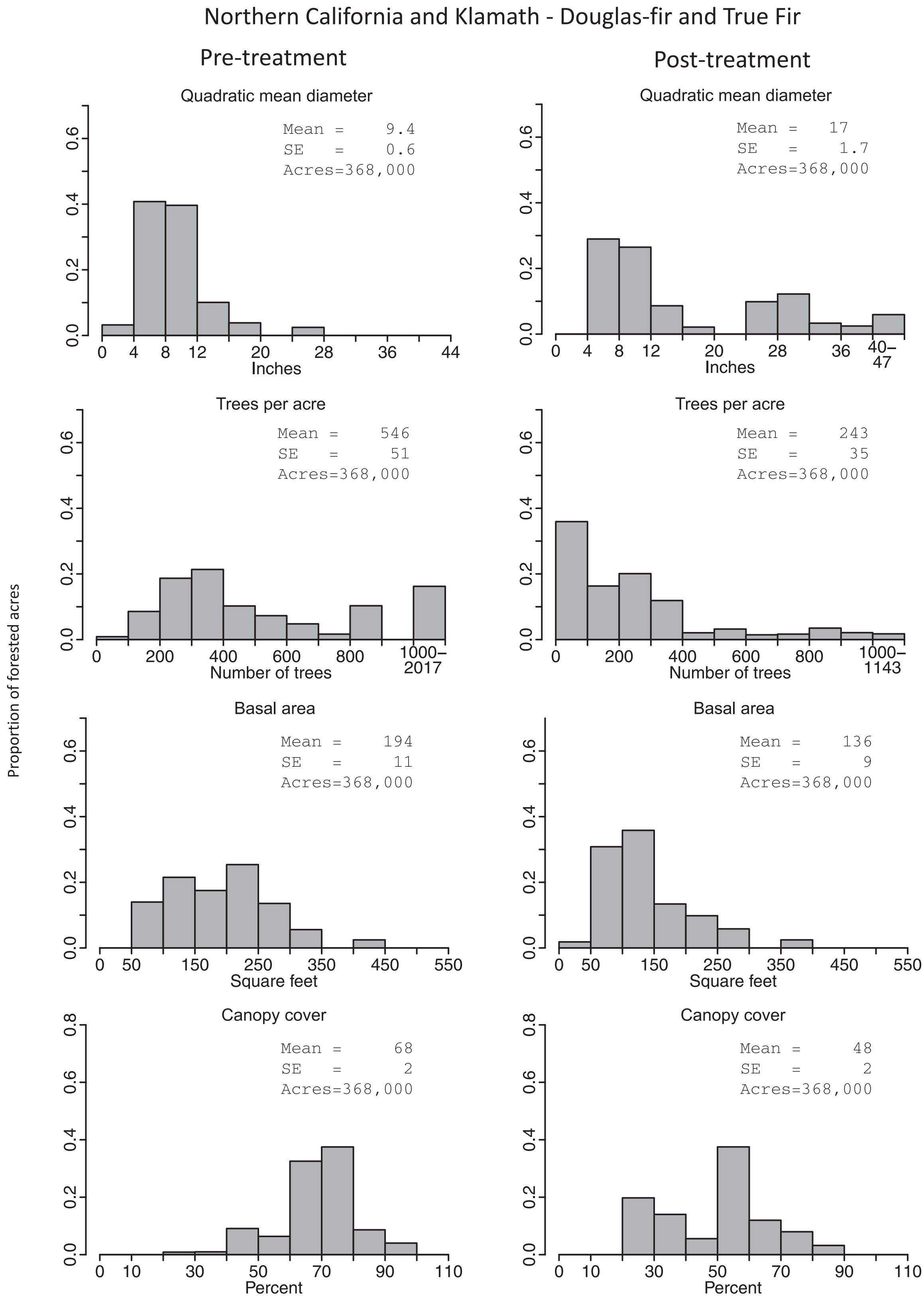

North and Central Rocky Mountains - Hazard score
Pre-treatment
Post-treatment
Hazard score - Douglas-fir & true fir
Mean = 1.9
SE = 0.1
Acres=768,000
Mean = 0.7
SE = 0.1
Acres=768,000
Hazard score
Hazard score - Pine and larch
Proportion of forested acres
Mean = 2.2
SE = 0.3
Acres=104,000
Mean = 1.1
SE = 0.3
Acres=104,000
Hazard score
Hazard score - Other species
Mean = 3.2
SE = 0.1
Acres=563,000
Mean = 2
SE = 0.1
Acres=563,000
Hazard score

Utah- Hazard score

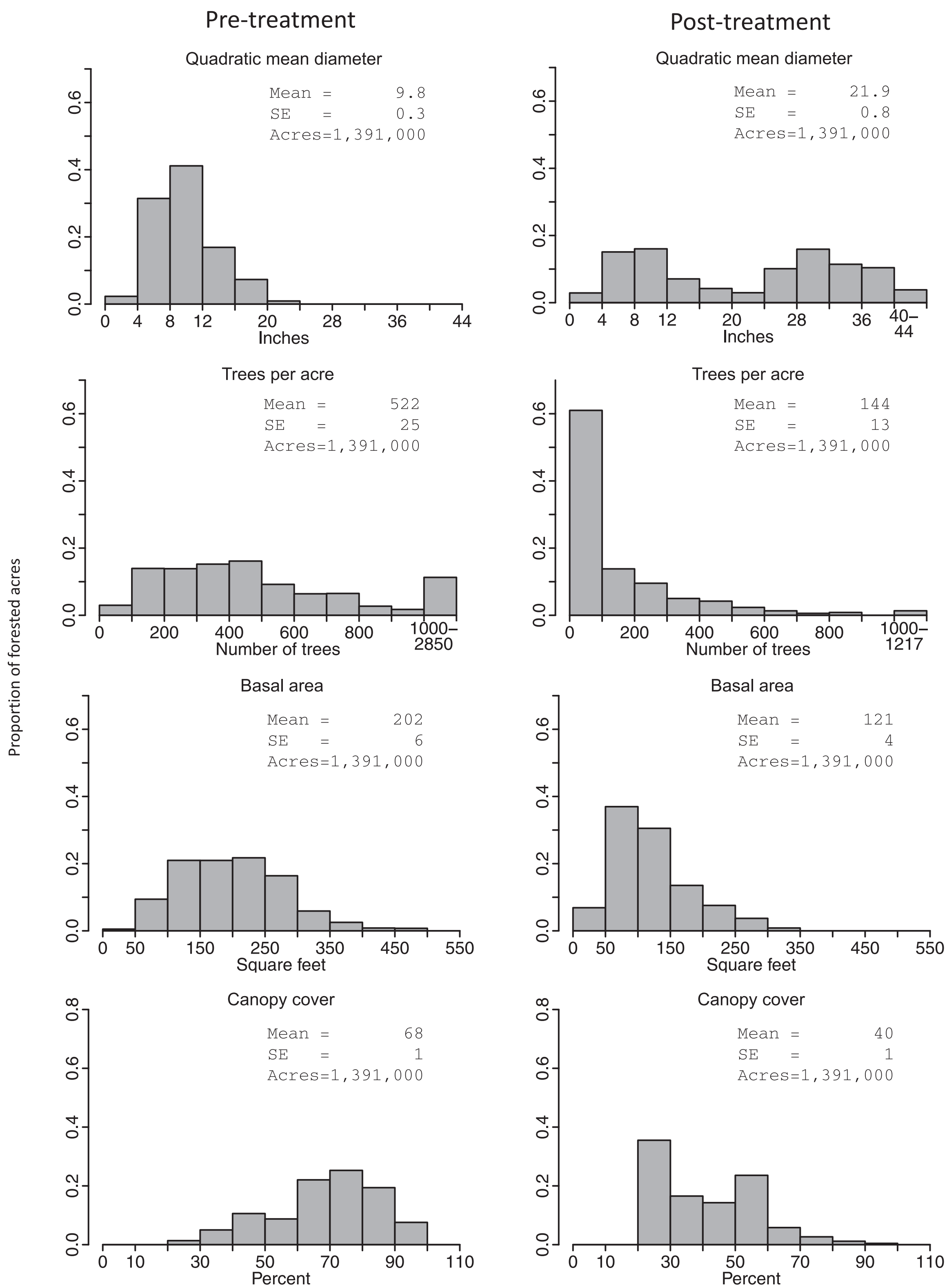


Stand Structure Metrics

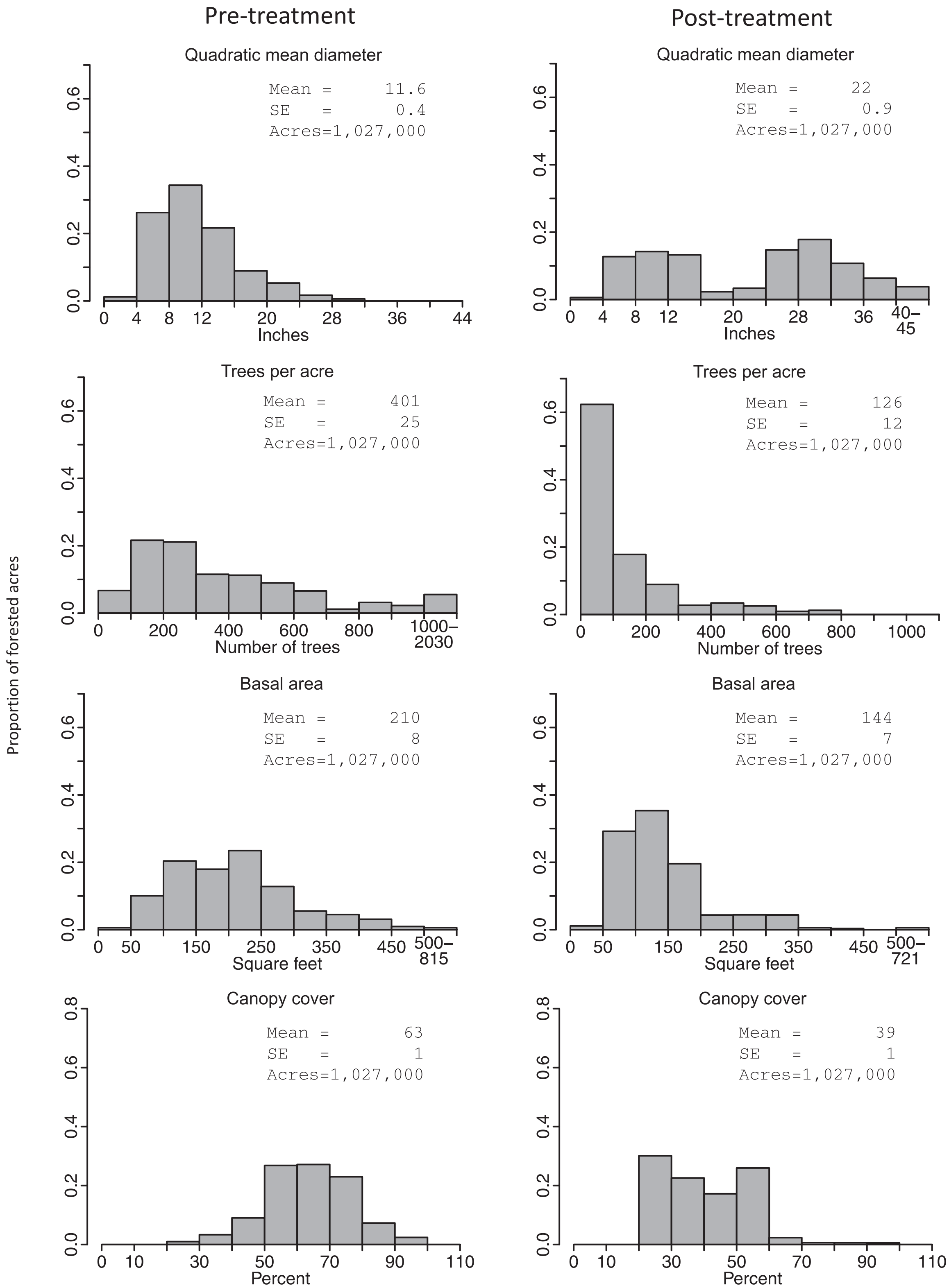



Northern California and Klamath - Douglas-fir and True Fir
Pre-treatment
Post-treatment
Proportion of forested acres
Quadratic mean diameter
Mean = 9.4
SE = 0.6
Acres=368,000
Inches
Quadratic mean diameter
Mean = 17
SE = 1.7
Acres=368,000
Inches
Trees per acre
Mean = 546
SE = 51
Acres=368,000
Number of trees
Trees per acre
Mean = 243
SE = 35
Acres=368,000
Number of trees
Basal area
Mean = 194
SE = 11
Acres=368,000
Square feet
Basal area
Mean = 136
SE = 9
Acres=368,000
Square feet
Canopy cover
Mean = 68
SE = 2
Acres=368,000
Percent
Canopy cover
Mean = 48
SE = 2
Acres=368,000
Percent

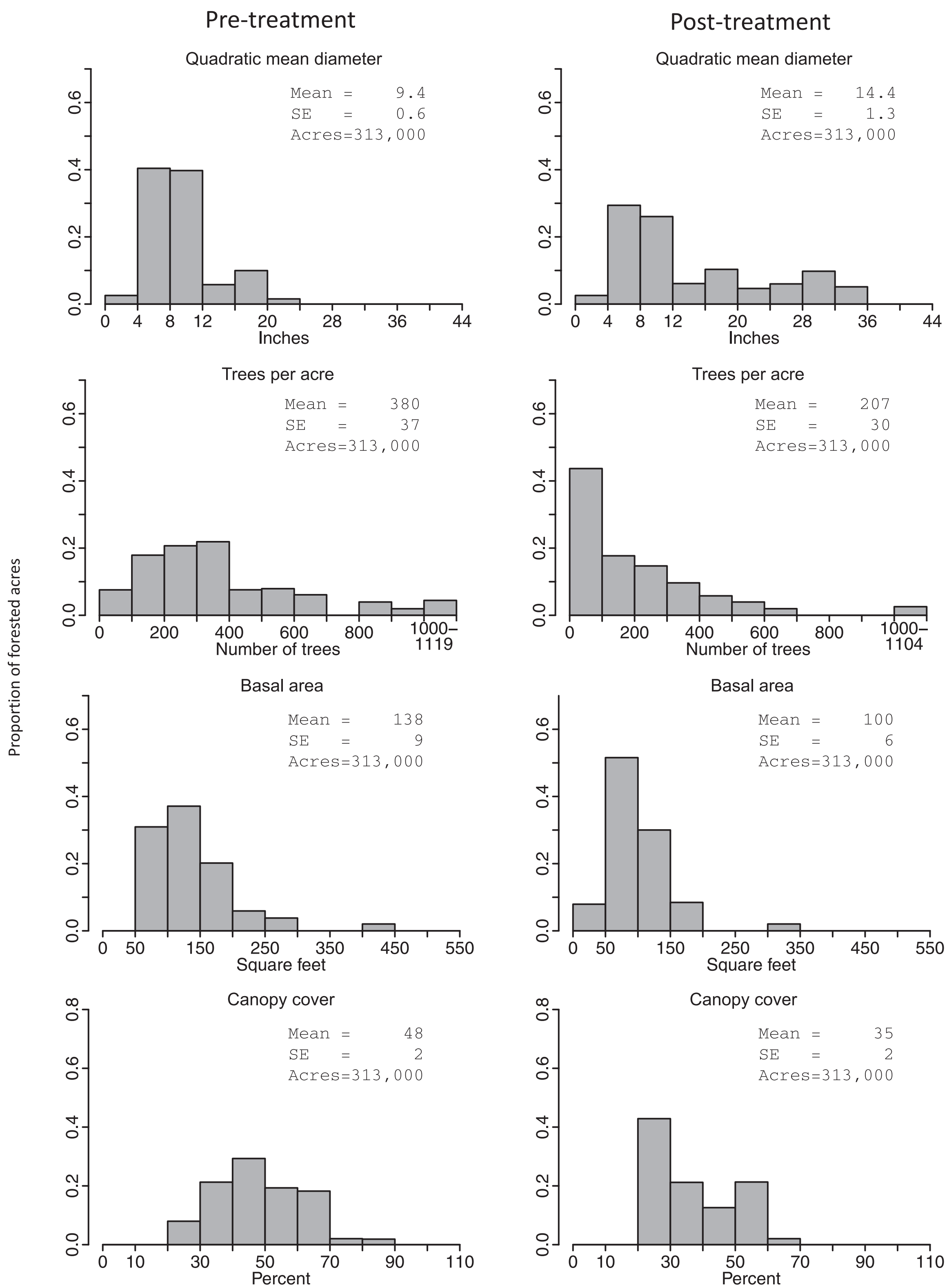
Northern California and Klamath - Other Species



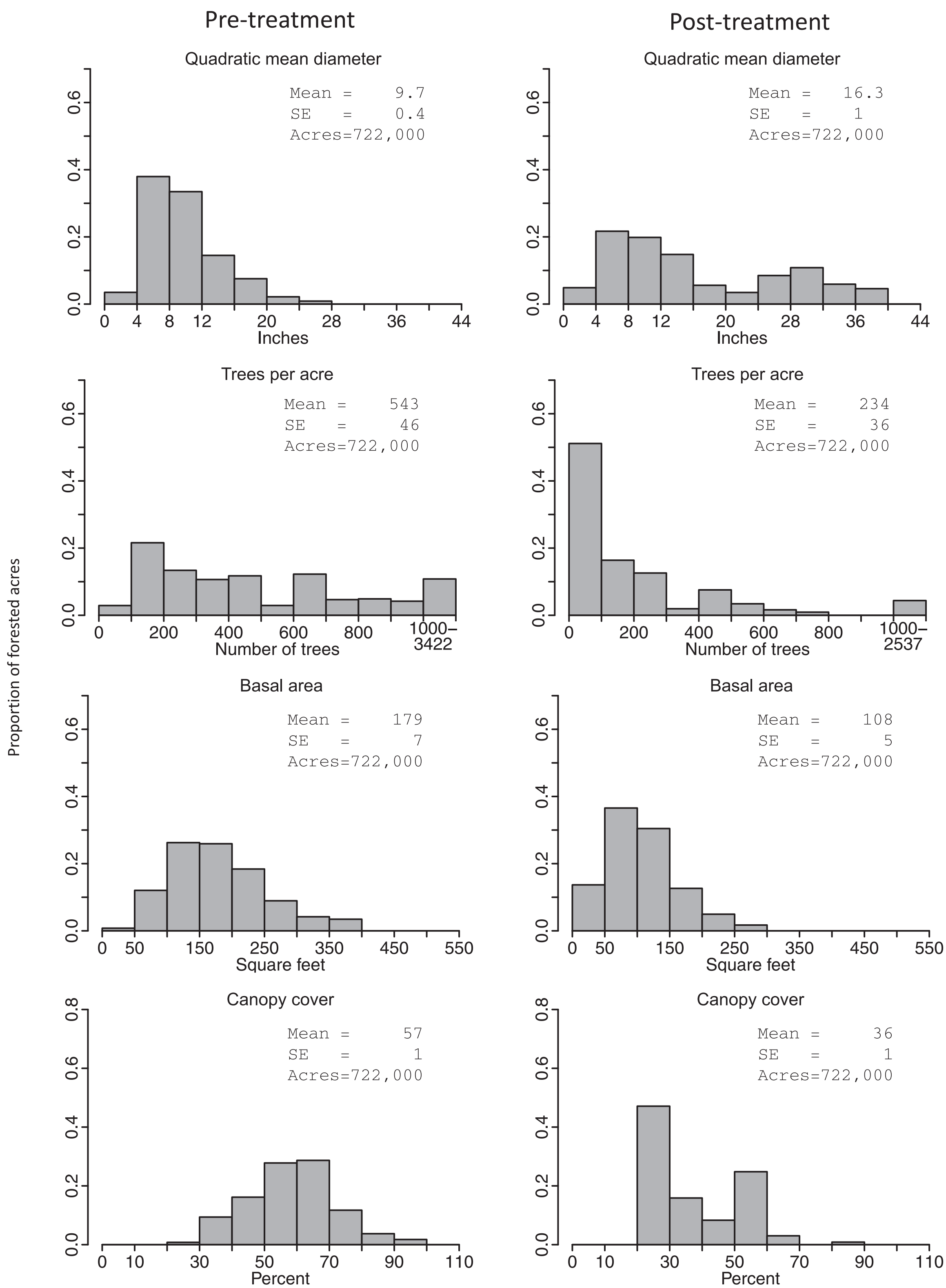
Pacific Northwest Interior -Douglas-fir and True Fir



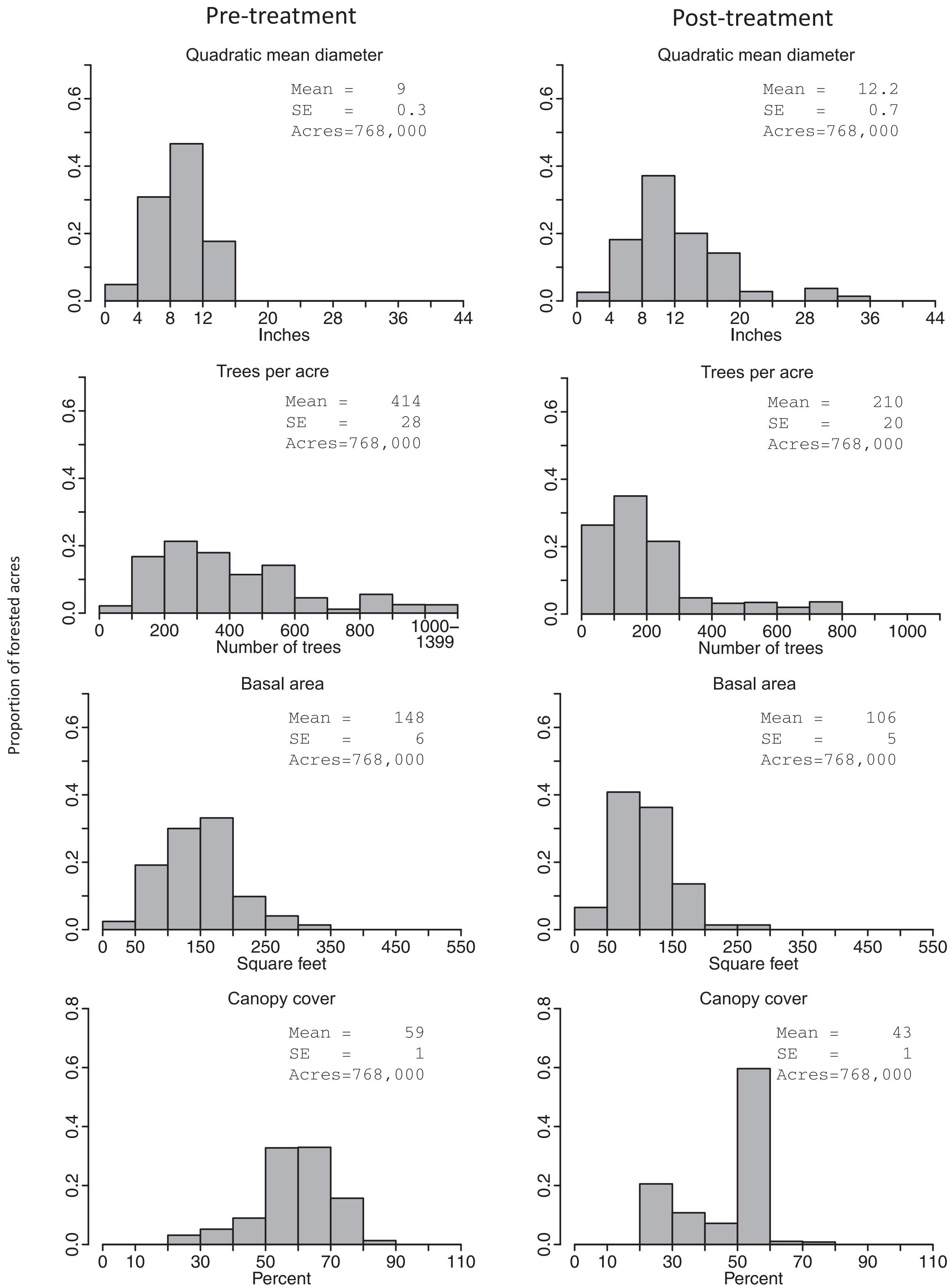
Pacific Northwest Interior - Pine and Western Larch



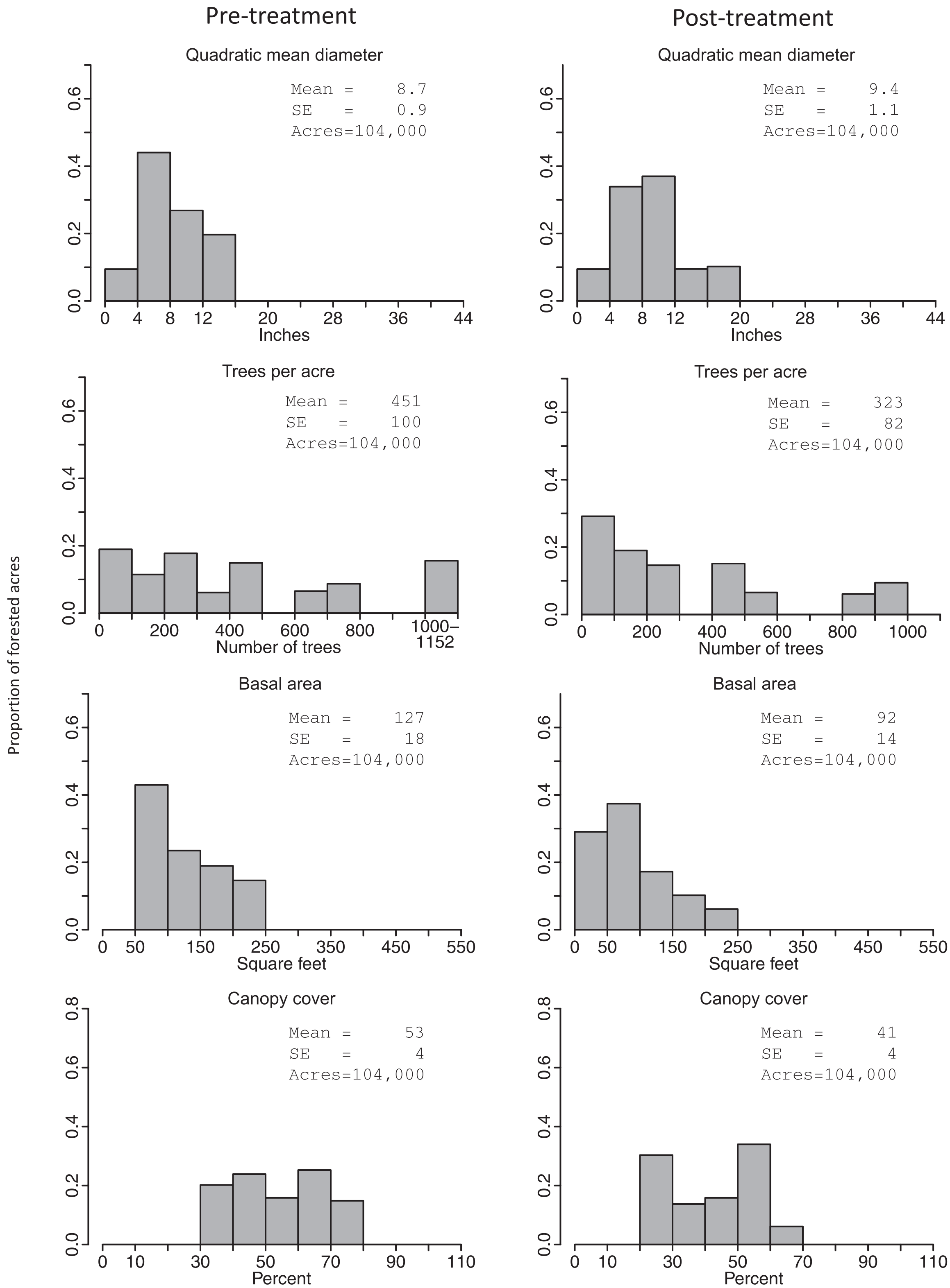
Pacific Northwest Interior - Other species



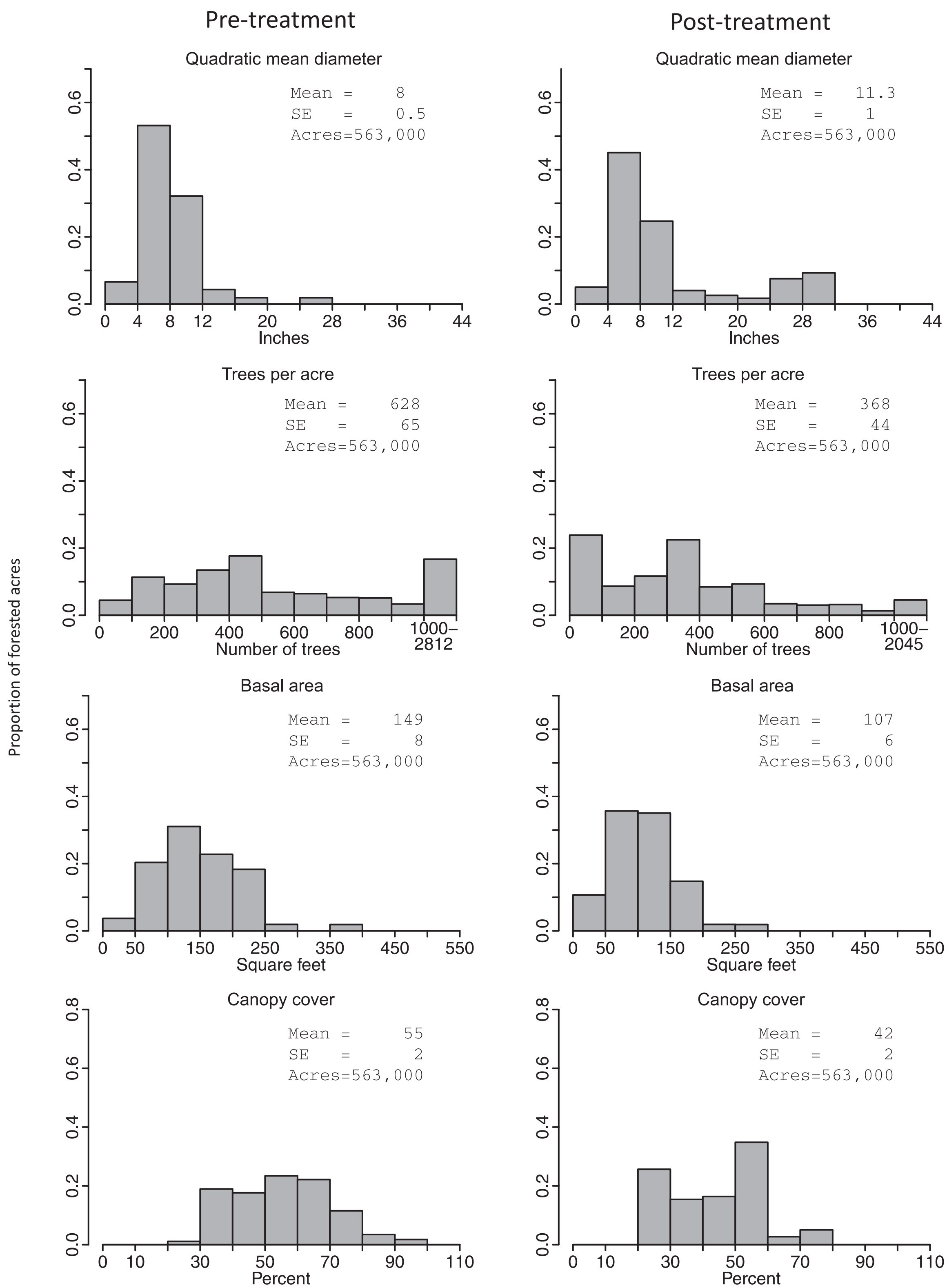
North and Central Rocky Mountains - Douglas-fir and True Fir



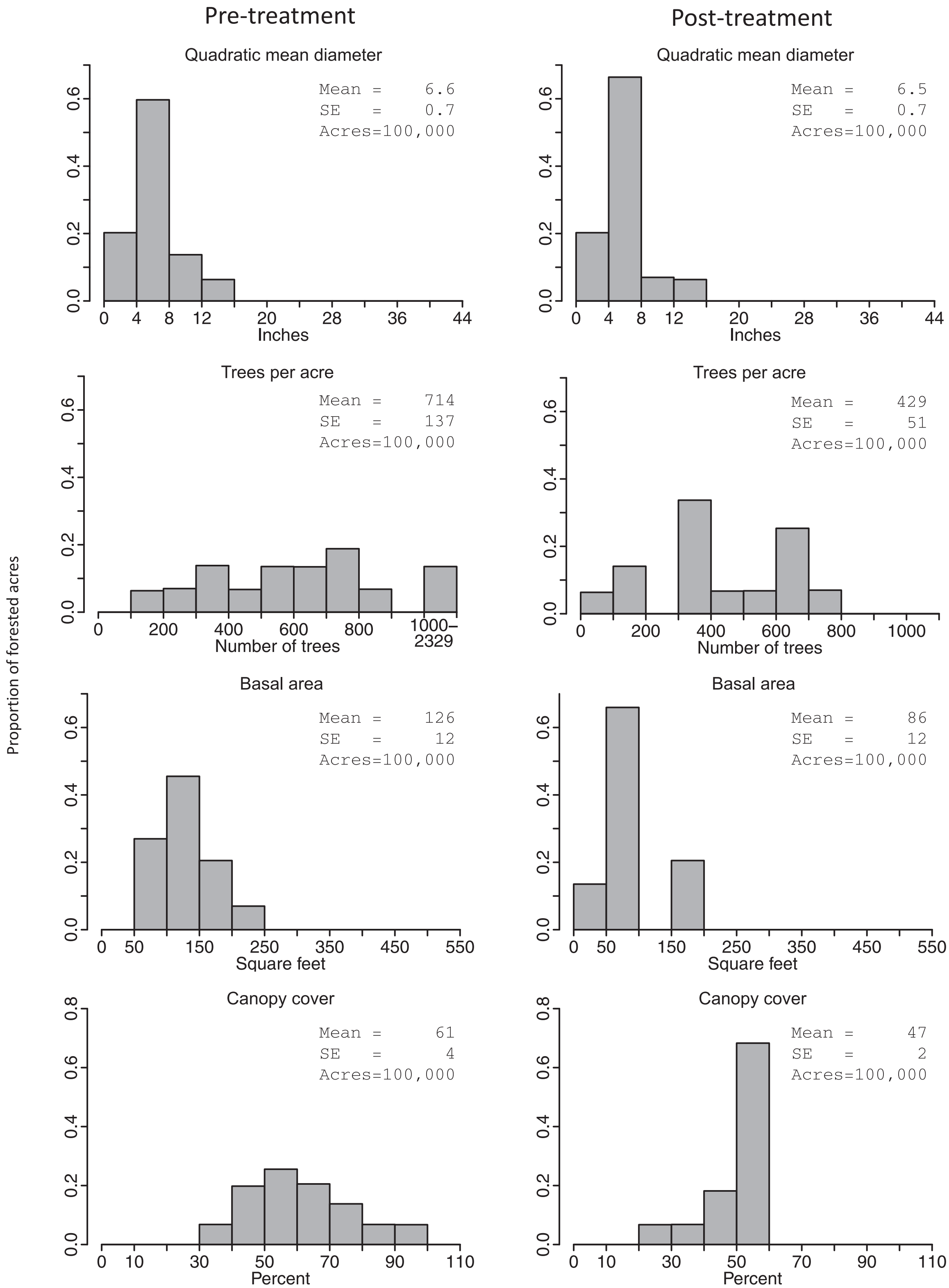
North and Central Rocky Mountains - Pine and Western larch



North and Central Rocky Mountains - Other Species

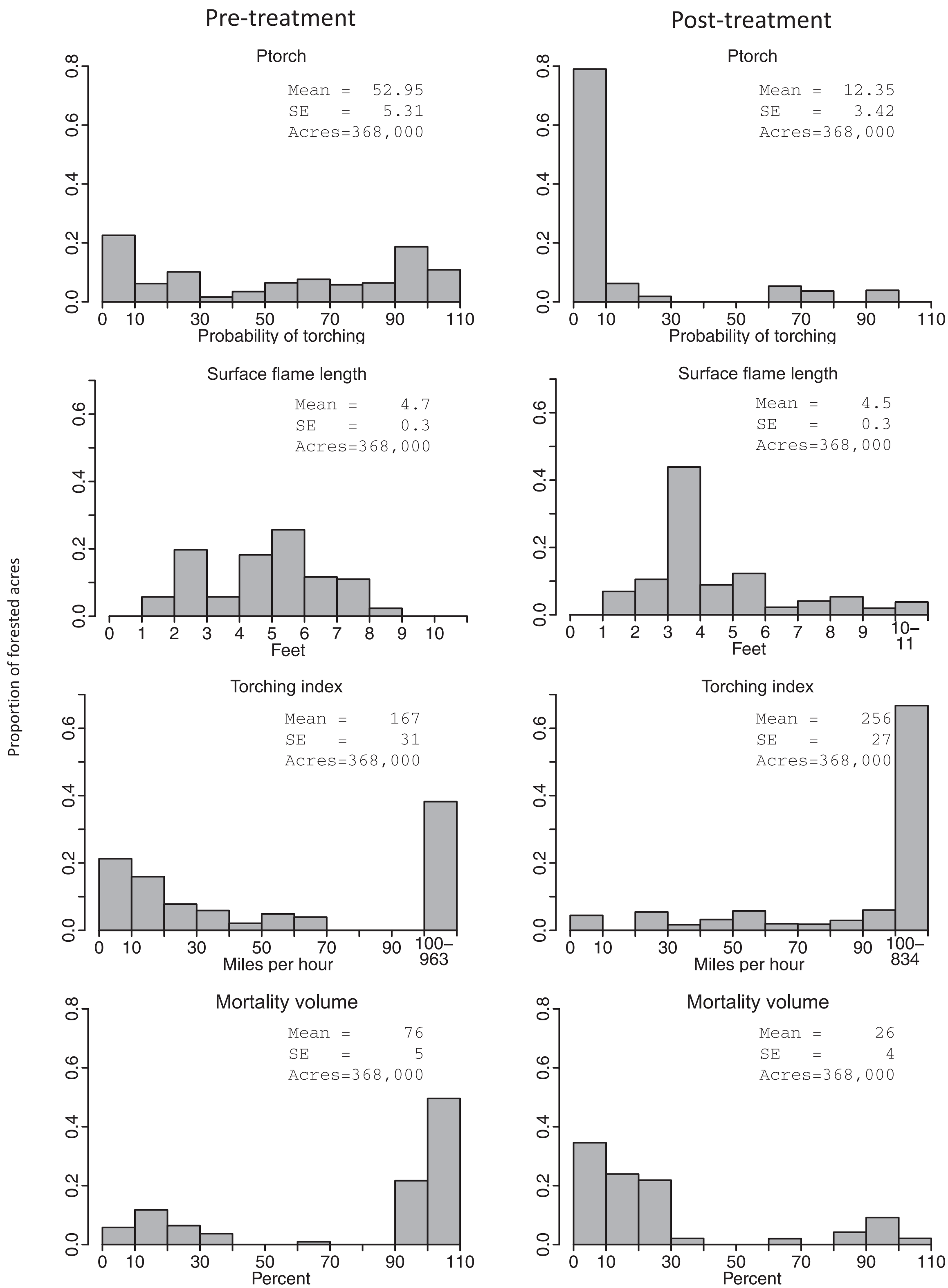


Utah - Other Species

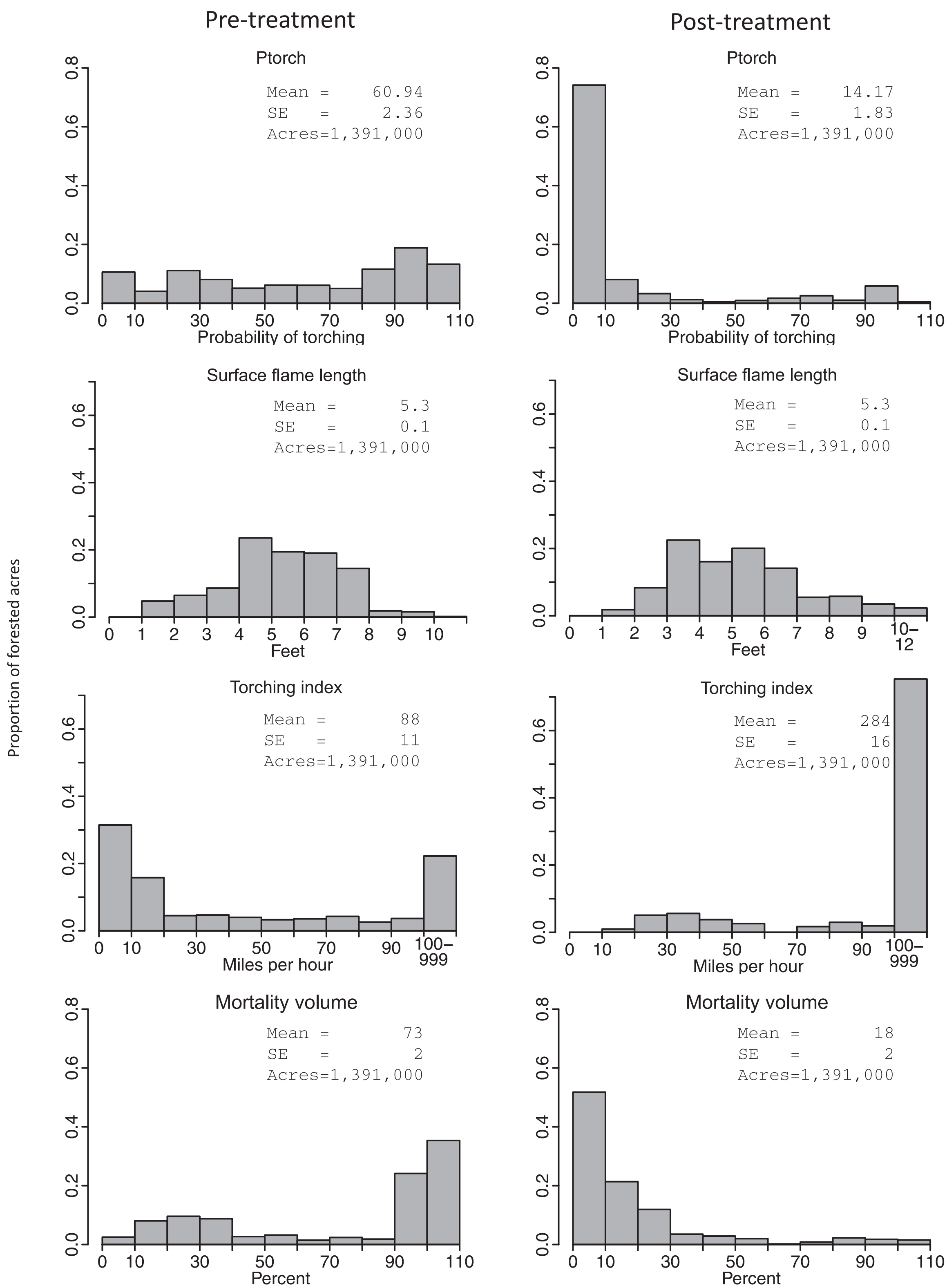


Fire Hazard Metrics

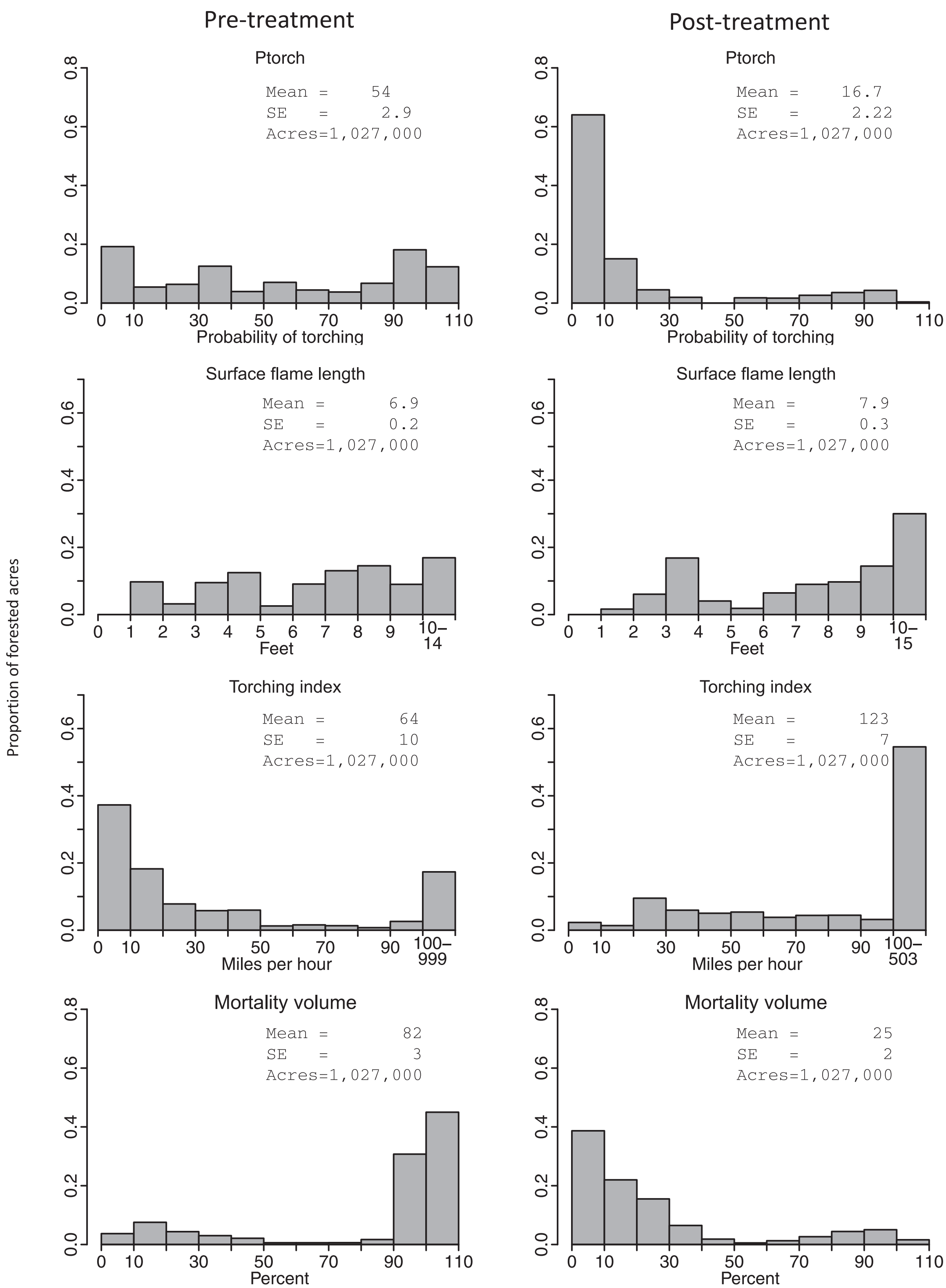
Northern California and Klamath - Douglis-fir and True Fir



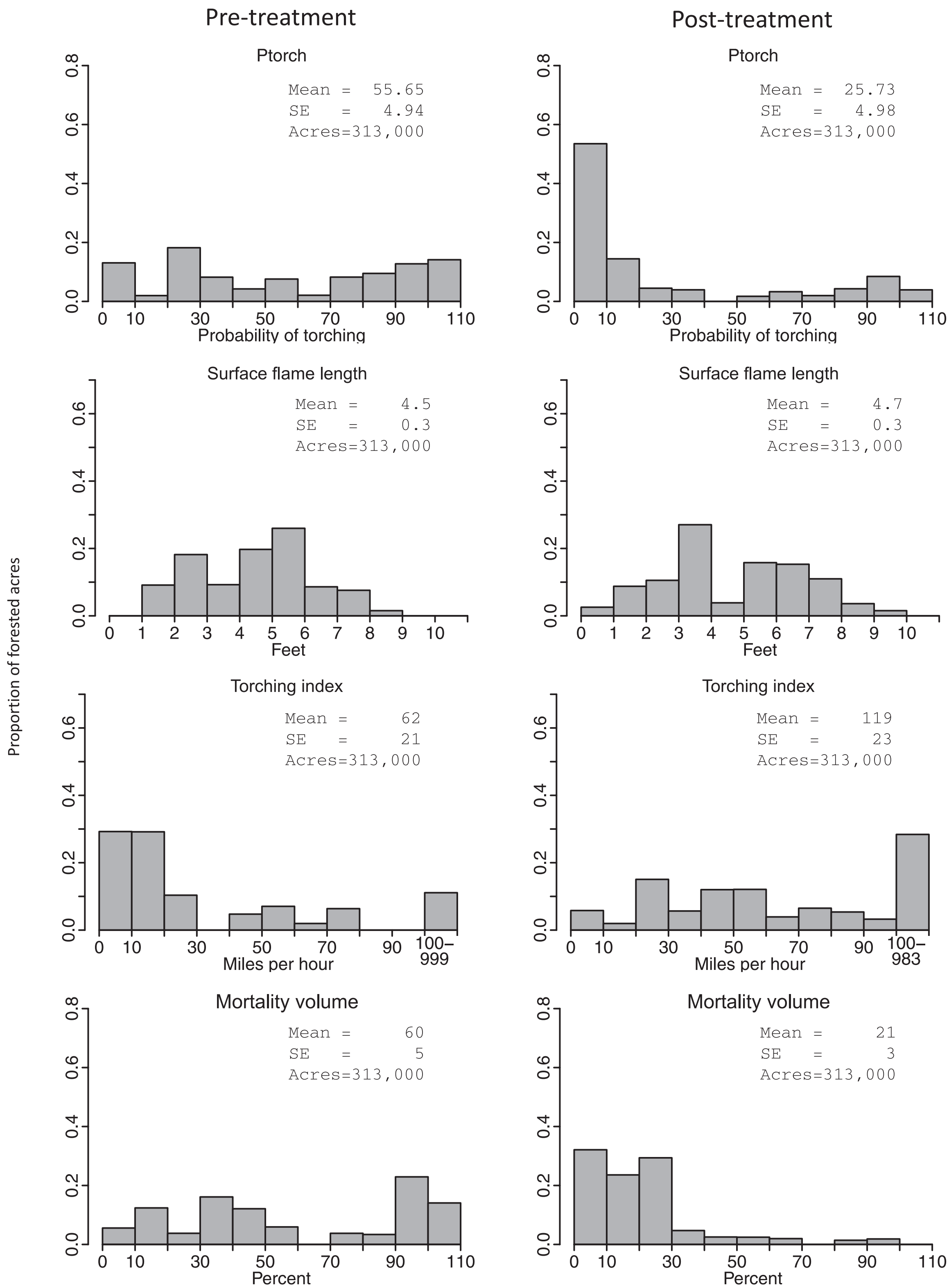
Northern California and Klamath - Other Species

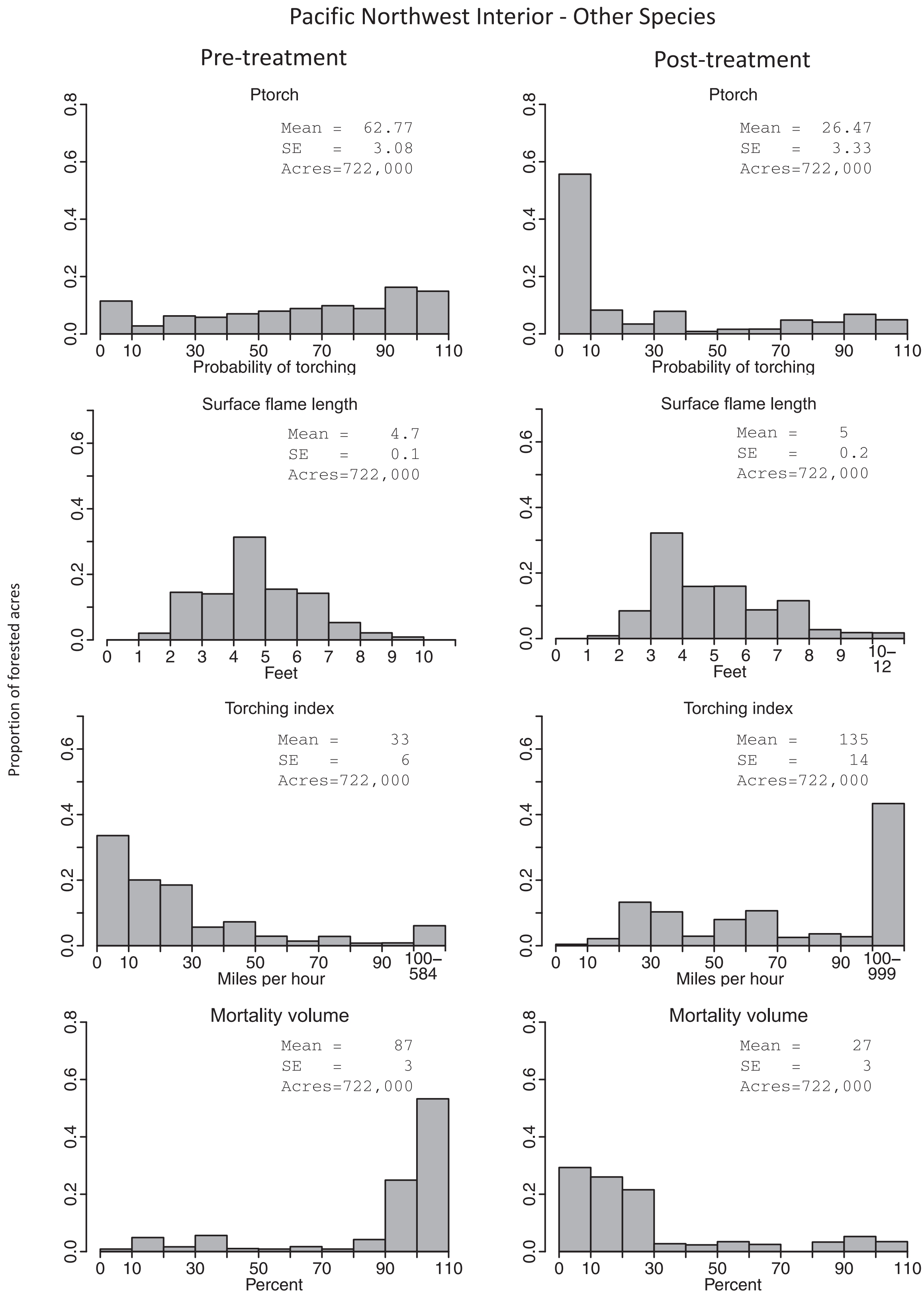


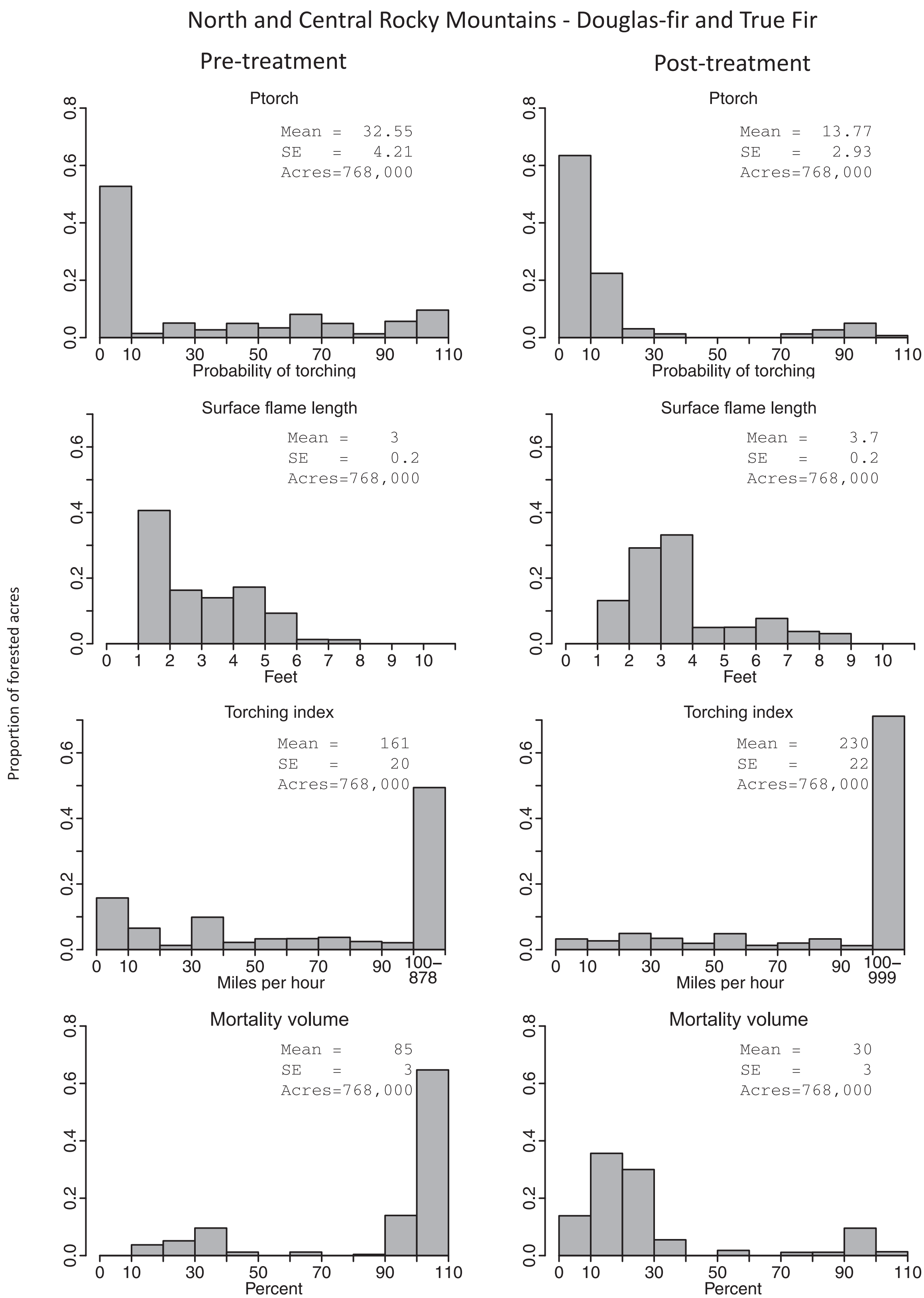
Pacific Northwest Interior - Douglas-fir and True Fir

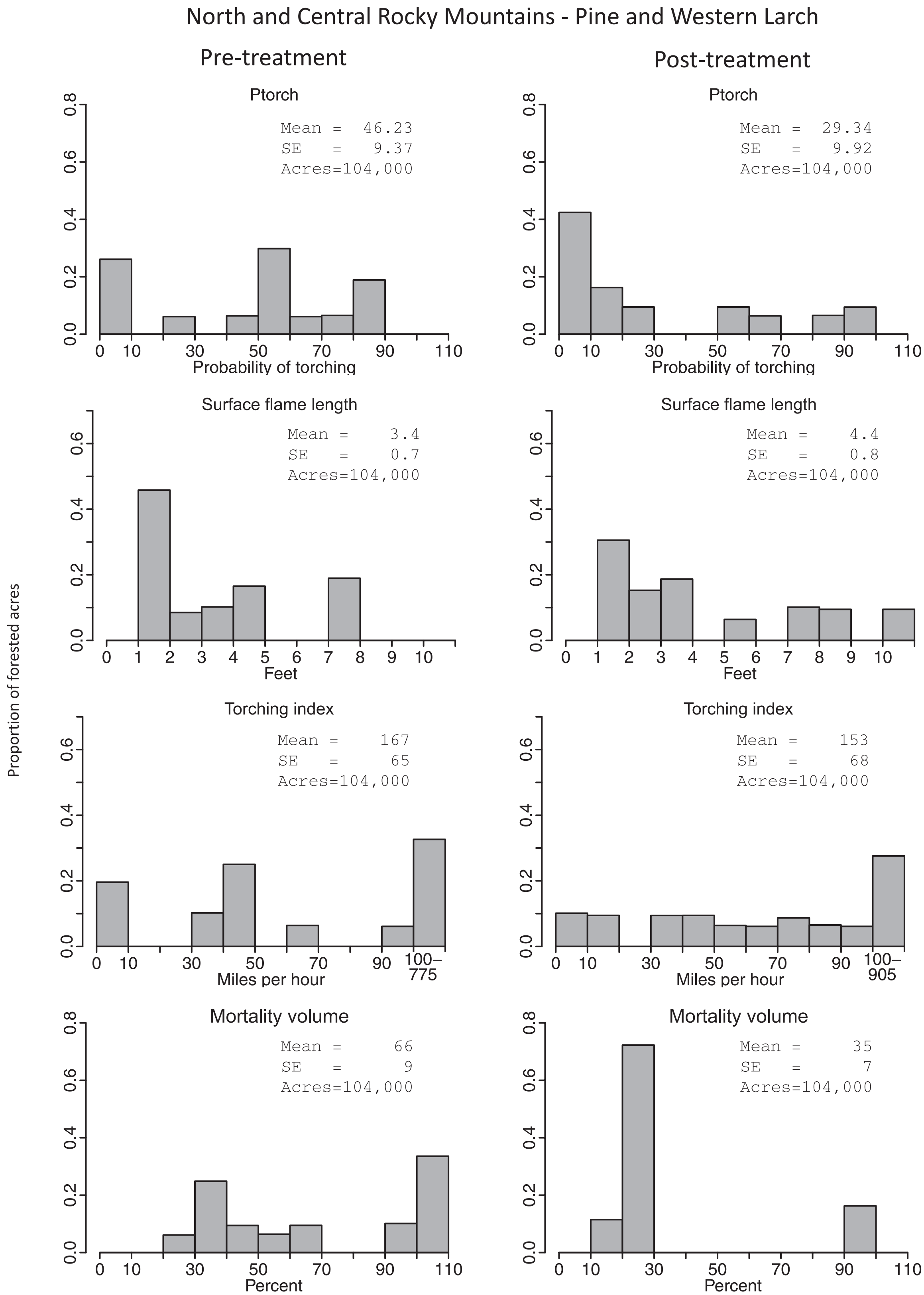


Pacific Northwest Interior - Pine and Western Larch

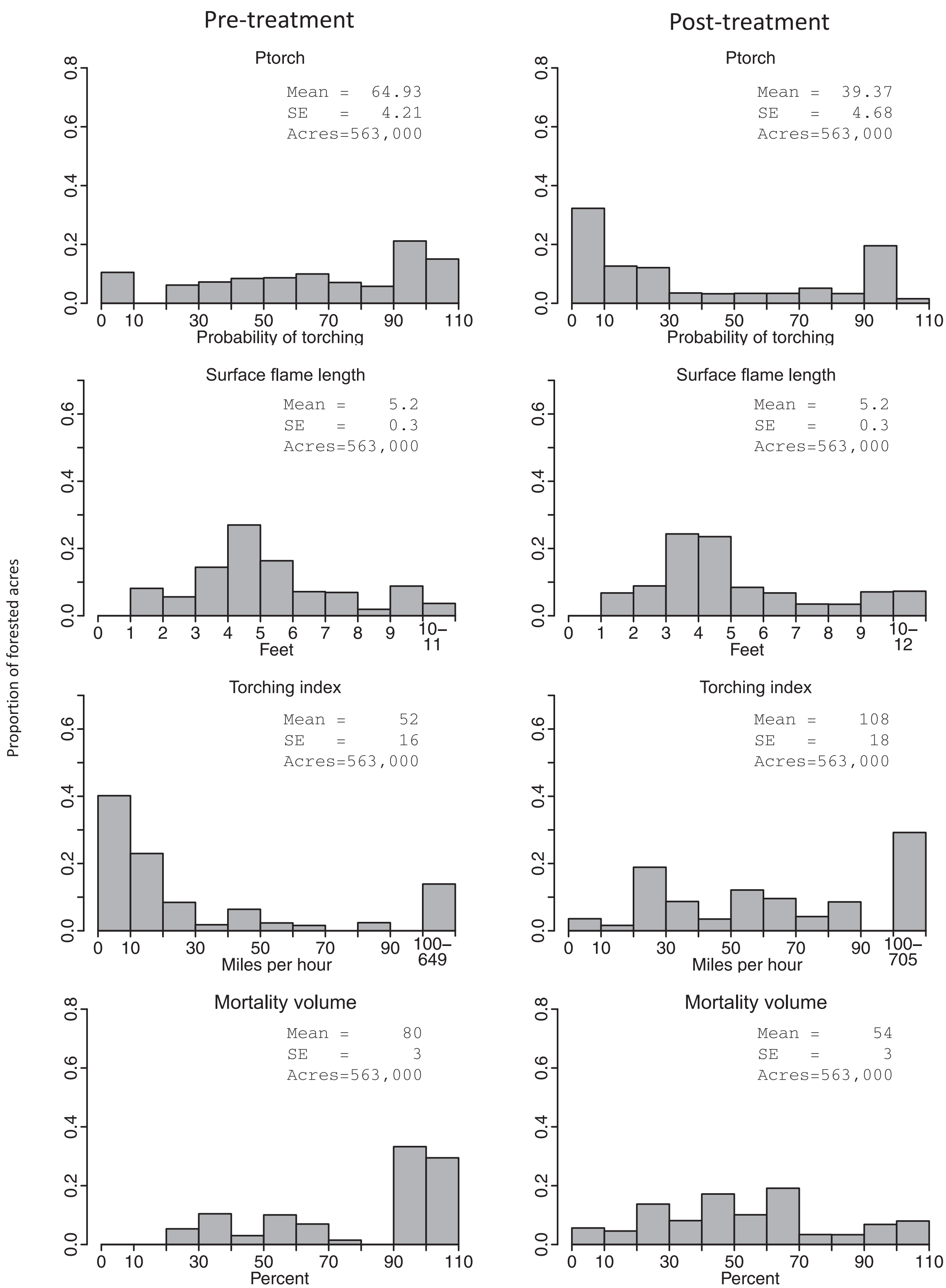


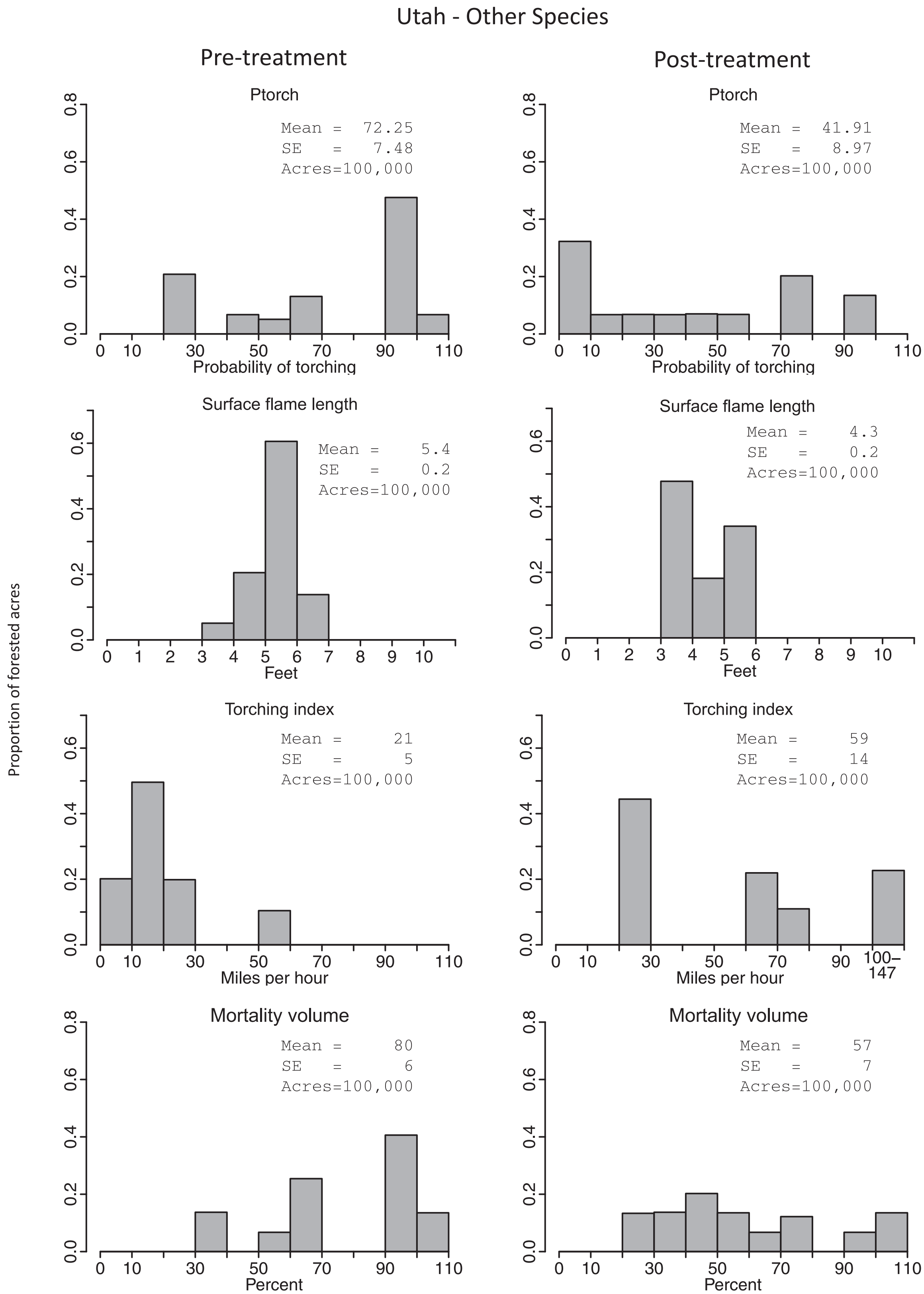

Pacific Northwest Interior - Other Species
Pre-treatment
Post-treatment
Proportion of forested acres
Ptorch
Mean = 62.77
SE = 3.08
Acres=722,000
Probability of torching
Ptorch
Mean = 26.47
SE = 3.33
Acres=722,000
Probability of torching
Surface flame length
Mean = 4.7
SE = 0.1
Acres=722,000
Feet
Surface flame length
Mean = 5
SE = 0.2
Acres=722,000
10–12
Feet
Torching index
Mean = 33
SE = 6
Acres=722,000
100–584
Miles per hour
Torching index
Mean = 135
SE = 14
Acres=722,000
100–999
Miles per hour
Mortality volume
Mean = 87
SE = 3
Acres=722,000
Percent
Mortality volume
Mean = 27
SE = 3
Acres=722,000
Percent


North and Central Rocky Mountains - Douglas-fir and True Fir
Pre-treatment
Post-treatment
Proportion of forested acres
Ptorch
Mean = 32.55
SE = 4.21
Acres=768,000
Probability of torching
Ptorch
Mean = 13.77
SE = 2.93
Acres=768,000
Probability of torching
Surface flame length
Mean = 3
SE = 0.2
Acres=768,000
Feet
Surface flame length
Mean = 3.7
SE = 0.2
Acres=768,000
Feet
Torching index
Mean = 161
SE = 20
Acres=768,000
Miles per hour
100–878
Torching index
Mean = 230
SE = 22
Acres=768,000
Miles per hour
100–999
Mortality volume
Mean = 85
SE = 3
Acres=768,000
Percent
Mortality volume
Mean = 30
SE = 3
Acres=768,000
Percent


North and Central Rocky Mountains - Pine and Western Larch
Pre-treatment
Post-treatment
Proportion of forested acres
Ptorch
Mean = 46.23
SE = 9.37
Acres=104,000
Probability of torching
Ptorch
Mean = 29.34
SE = 9.92
Acres=104,000
Probability of torching
Surface flame length
Mean = 3.4
SE = 0.7
Acres=104,000
Feet
Surface flame length
Mean = 4.4
SE = 0.8
Acres=104,000
Feet
Torching index
Mean = 167
SE = 65
Acres=104,000
Miles per hour
100–775
Torching index
Mean = 153
SE = 68
Acres=104,000
Miles per hour
100–905
Mortality volume
Mean = 66
SE = 9
Acres=104,000
Percent
Mortality volume
Mean = 35
SE = 7
Acres=104,000
Percent

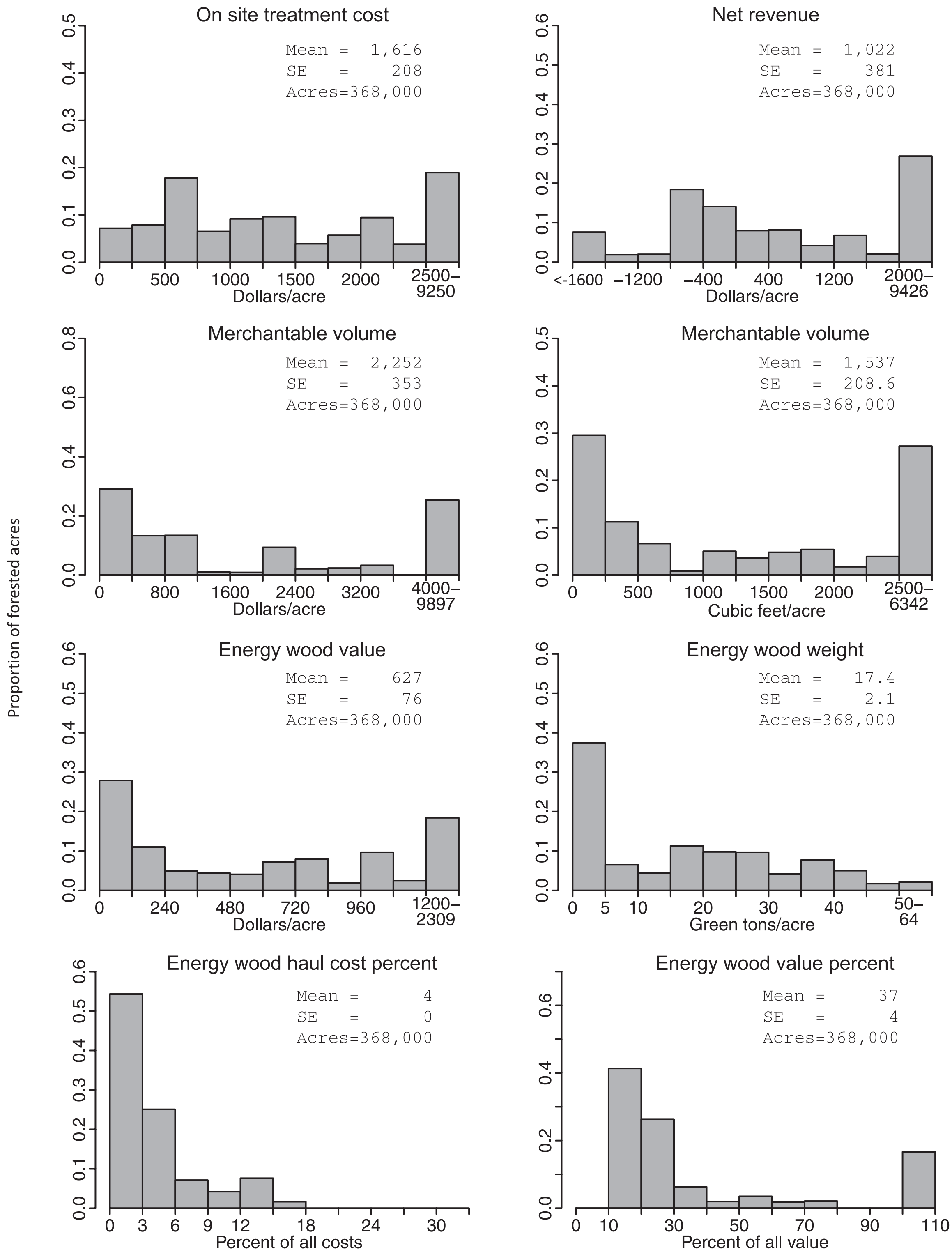
North and Central Rocky Mountains - Other Species



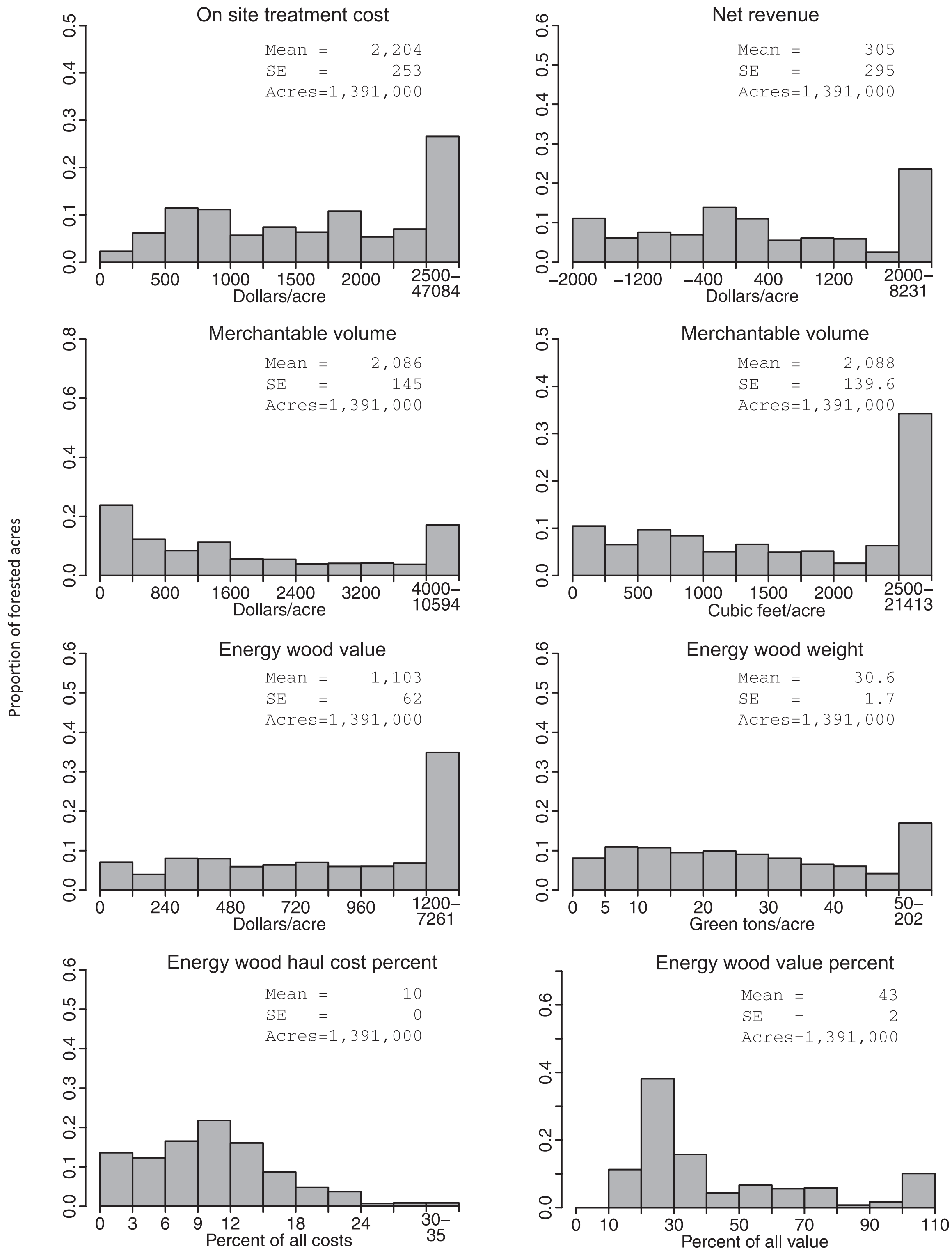

Utah - Other Species
Pre-treatment
Post-treatment
Proportion of forested acres
Ptorch
Mean = 72.25
SE = 7.48
Acres=100,000
Probability of torching
Ptorch
Mean = 41.91
SE = 8.97
Acres=100,000
Probability of torching
Surface flame length
Mean = 5.4
SE = 0.2
Acres=100,000
Feet
Surface flame length
Mean = 4.3
SE = 0.2
Acres=100,000
Feet
Torching index
Mean = 21
SE = 5
Acres=100,000
Miles per hour
Torching index
Mean = 59
SE = 14
Acres=100,000
Miles per hour
100–147
Mortality volume
Mean = 80
SE = 6
Acres=100,000
Percent
Mortality volume
Mean = 57
SE = 7
Acres=100,000
Percent

Economic Implications

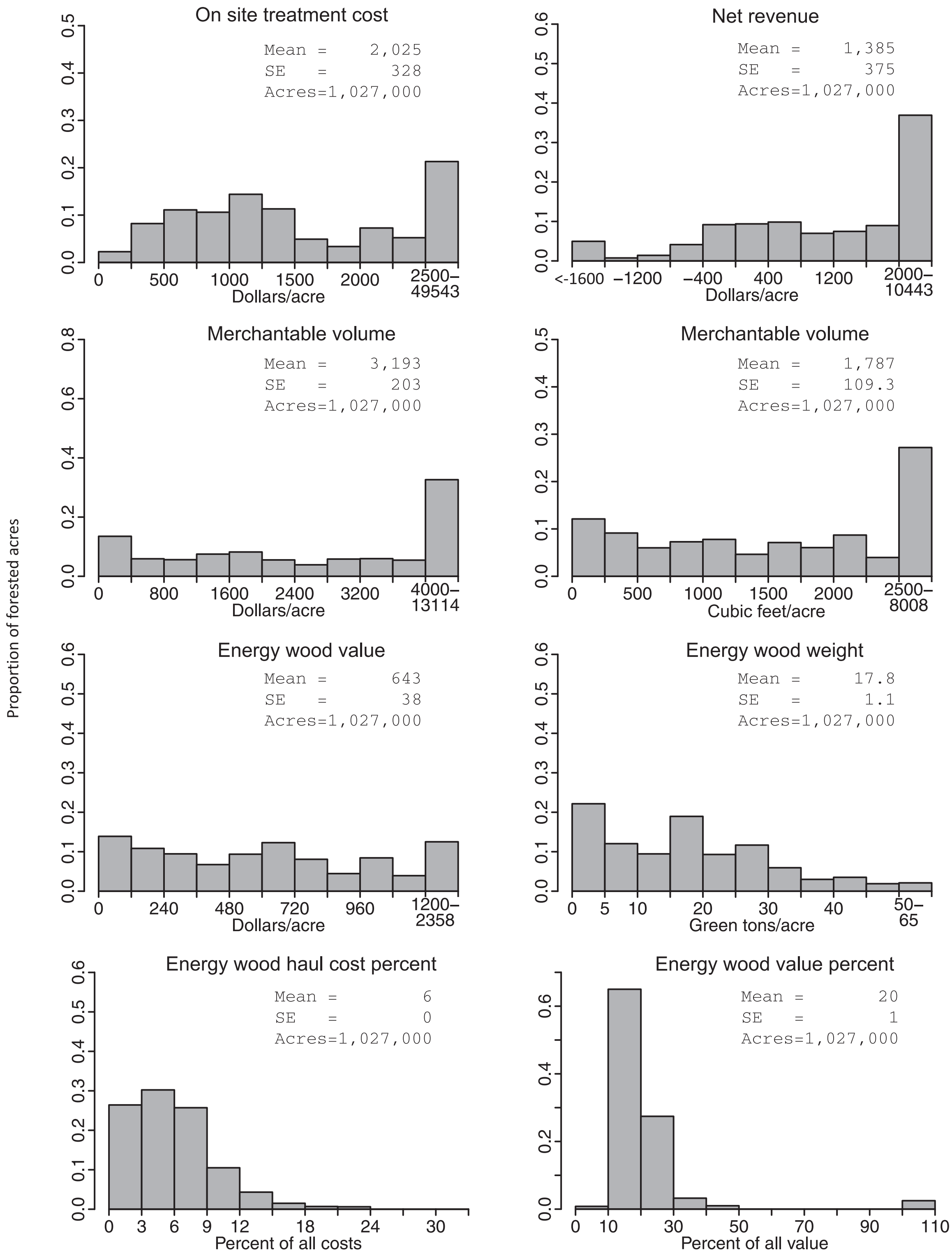
Northern California and Klamath - Douglas-fir and True Fir



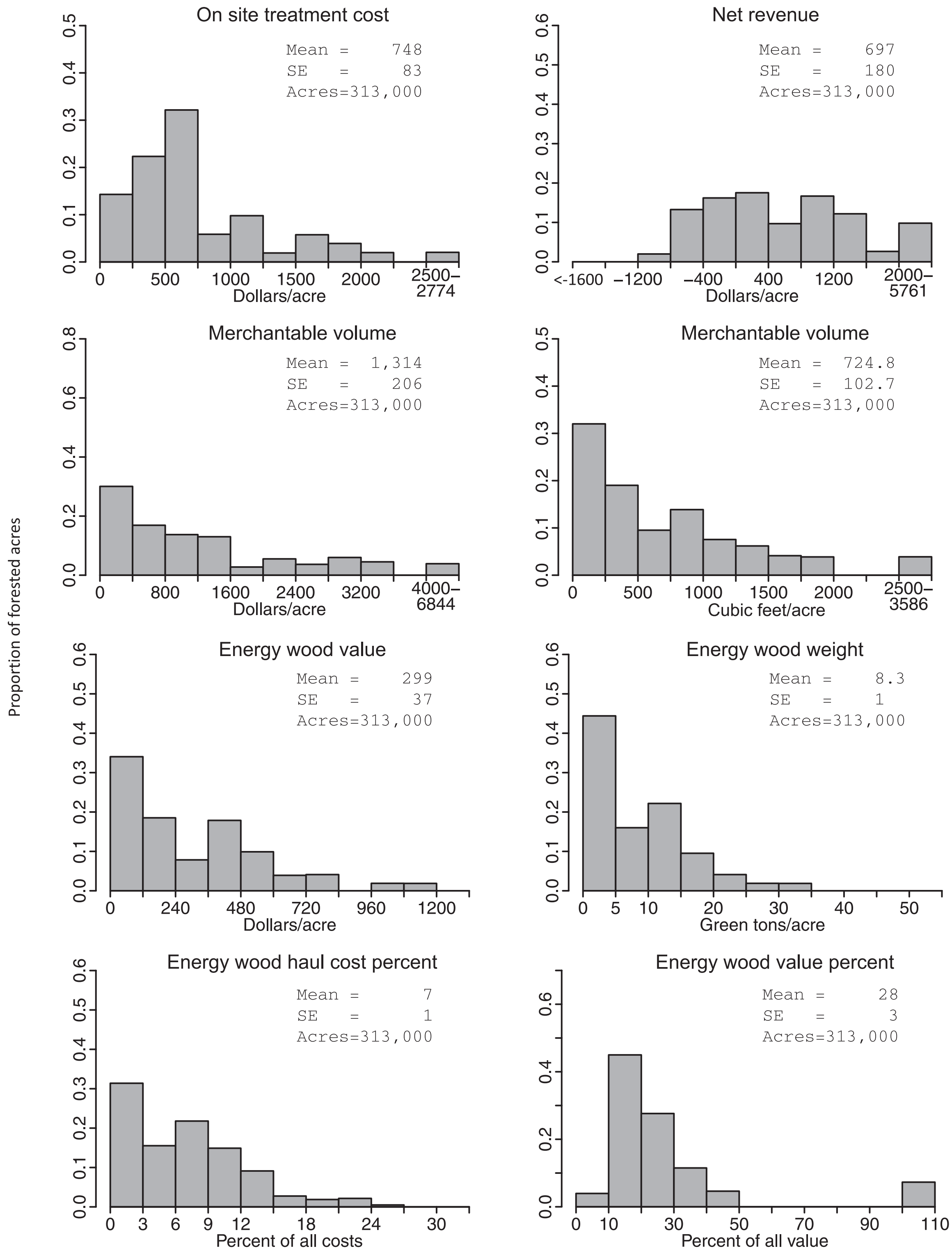
Northern California and Klamath - Other Species



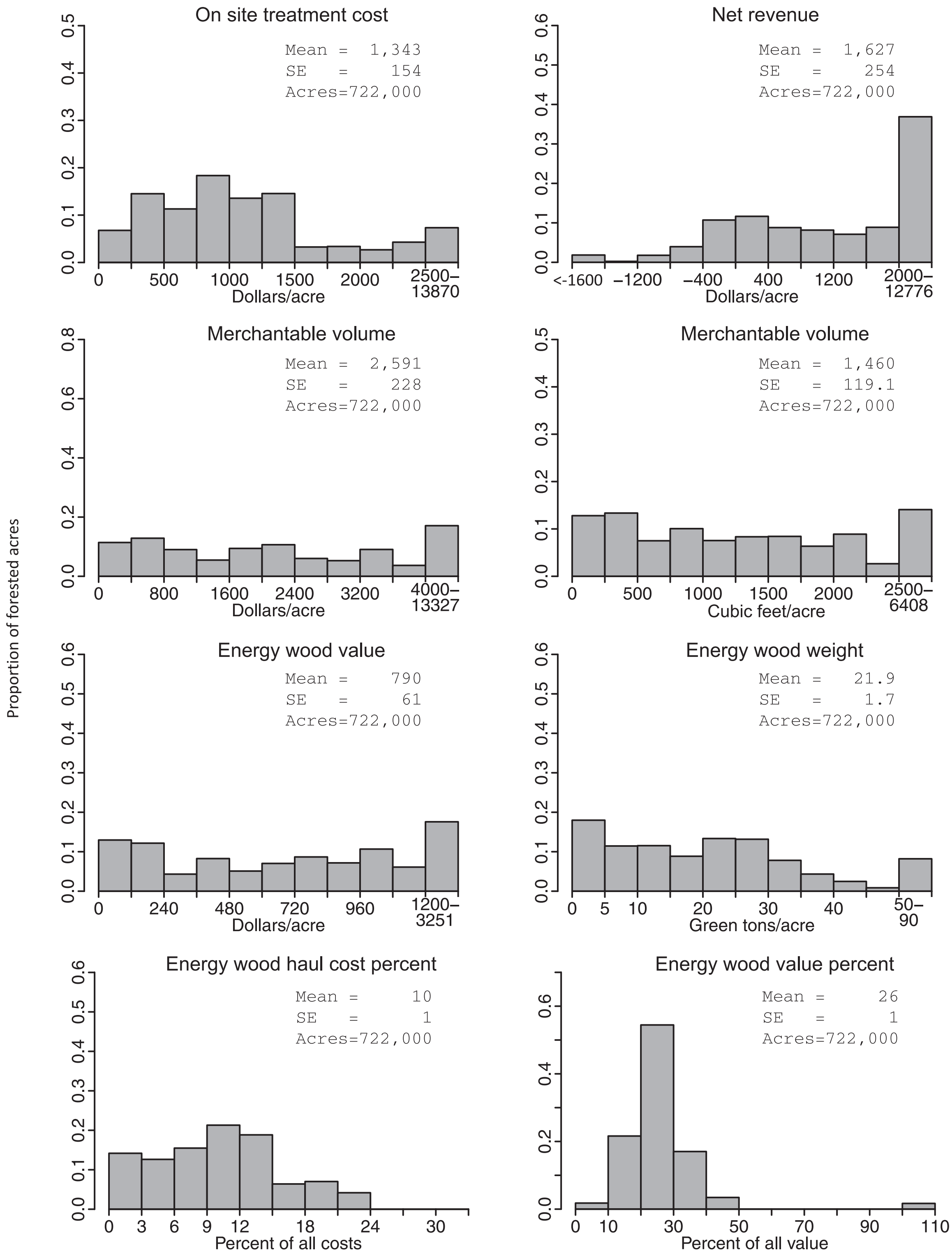
Pacific Northwest Interior - Douglas-fir and True Fir

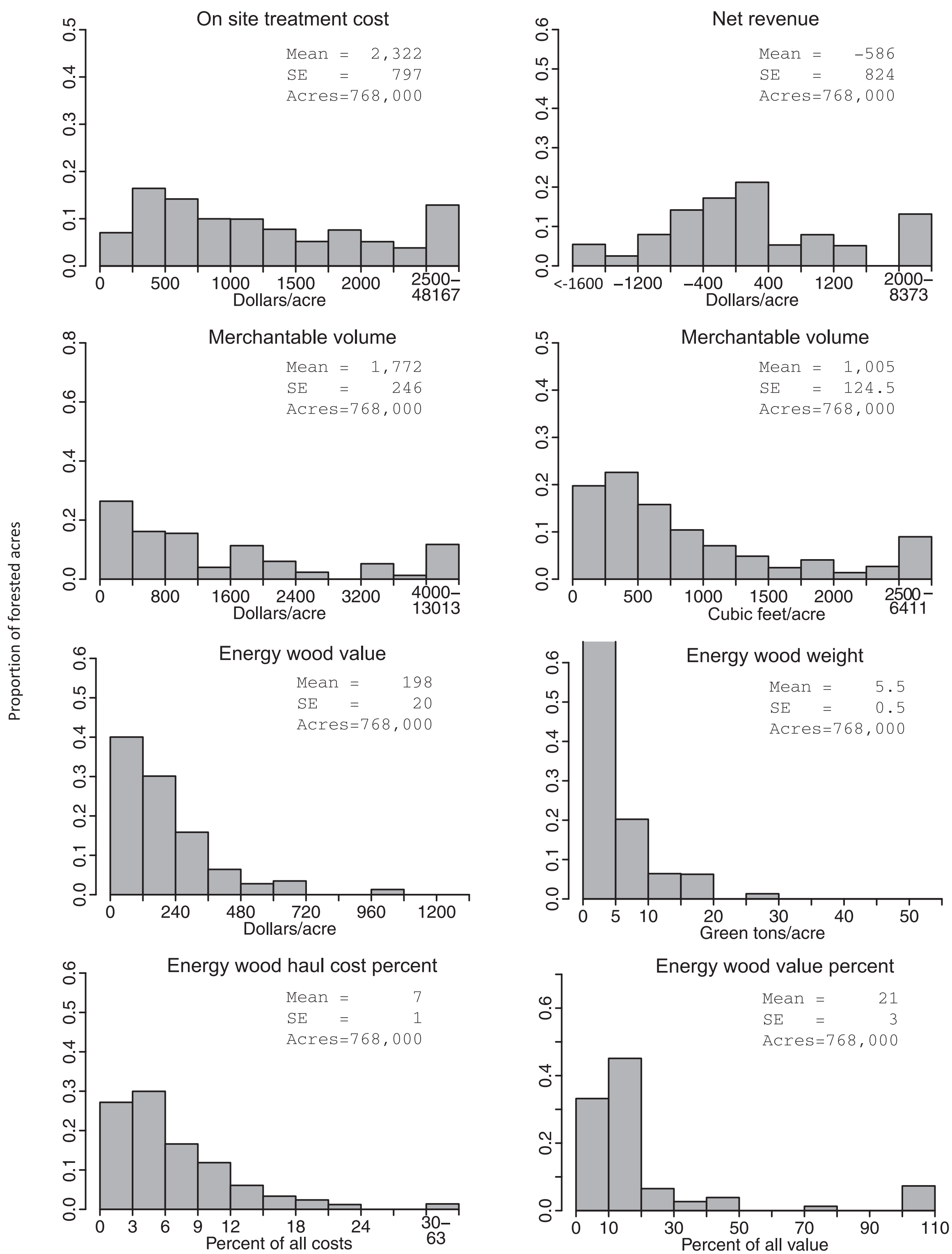


Pacific Northwest Interior - Pine and Western Larch



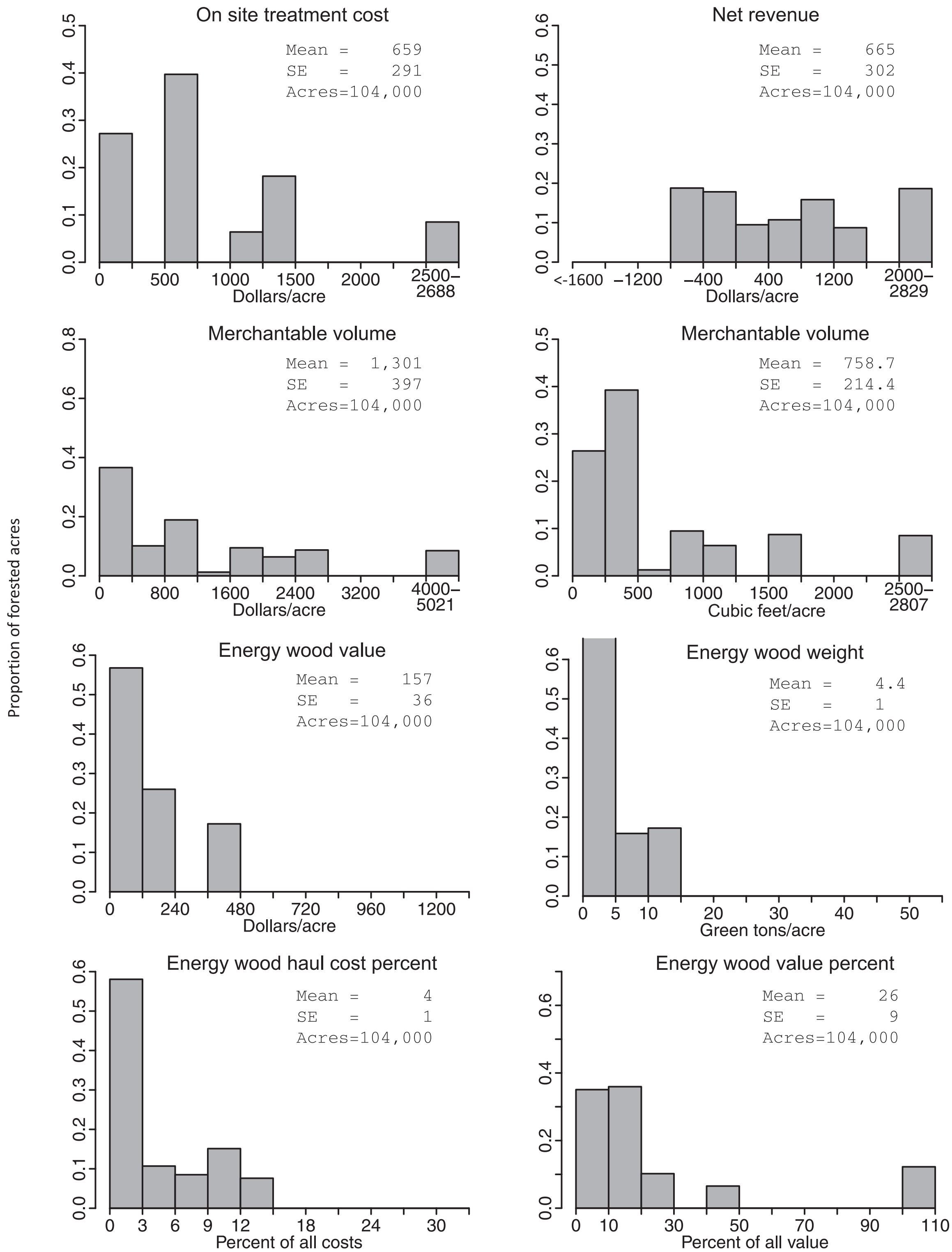
Pacific Northwest Interior - Other Species



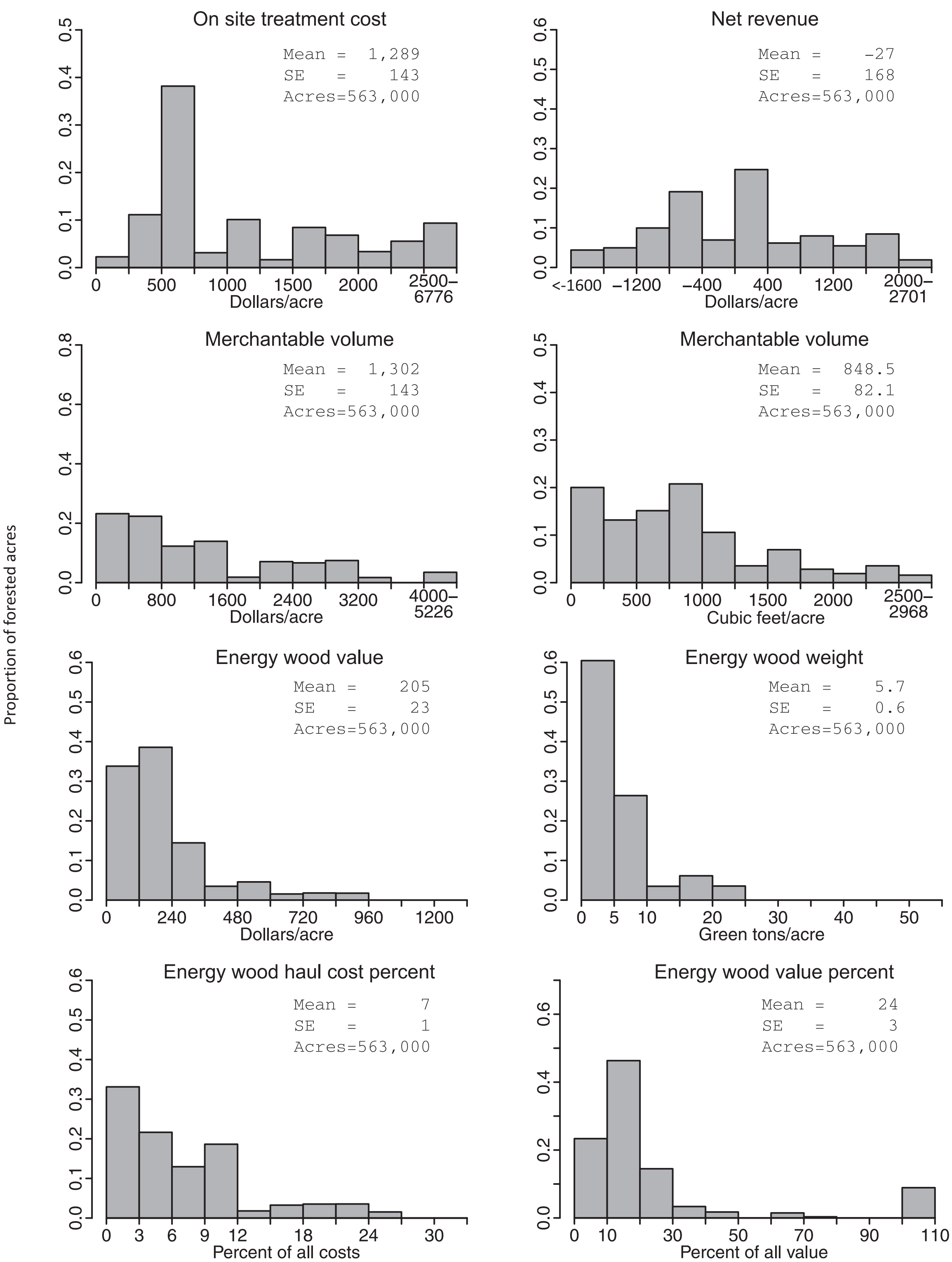


On site treatment cost
Mean = 2,322
SE = 797
Acres=768,000
Dollars/acre
Net revenue
Mean = -586
SE = 824
Acres=768,000
Dollars/acre
Merchantable volume
Mean = 1,772
SE = 246
Acres=768,000
Dollars/acre
Merchantable volume
Mean = 1,005
SE = 124.5
Acres=768,000
Cubic feet/acre
Energy wood value
Mean = 198
SE = 20
Acres=768,000
Dollars/acre
Energy wood weight
Mean = 5.5
SE = 0.5
Acres=768,000
Green tons/acre
Energy wood haul cost percent
Mean = 7
SE = 1
Acres=768,000
Percent of all costs
Energy wood value percent
Mean = 21
SE = 3
Acres=768,000
Percent of all value
Proportion of forested acres

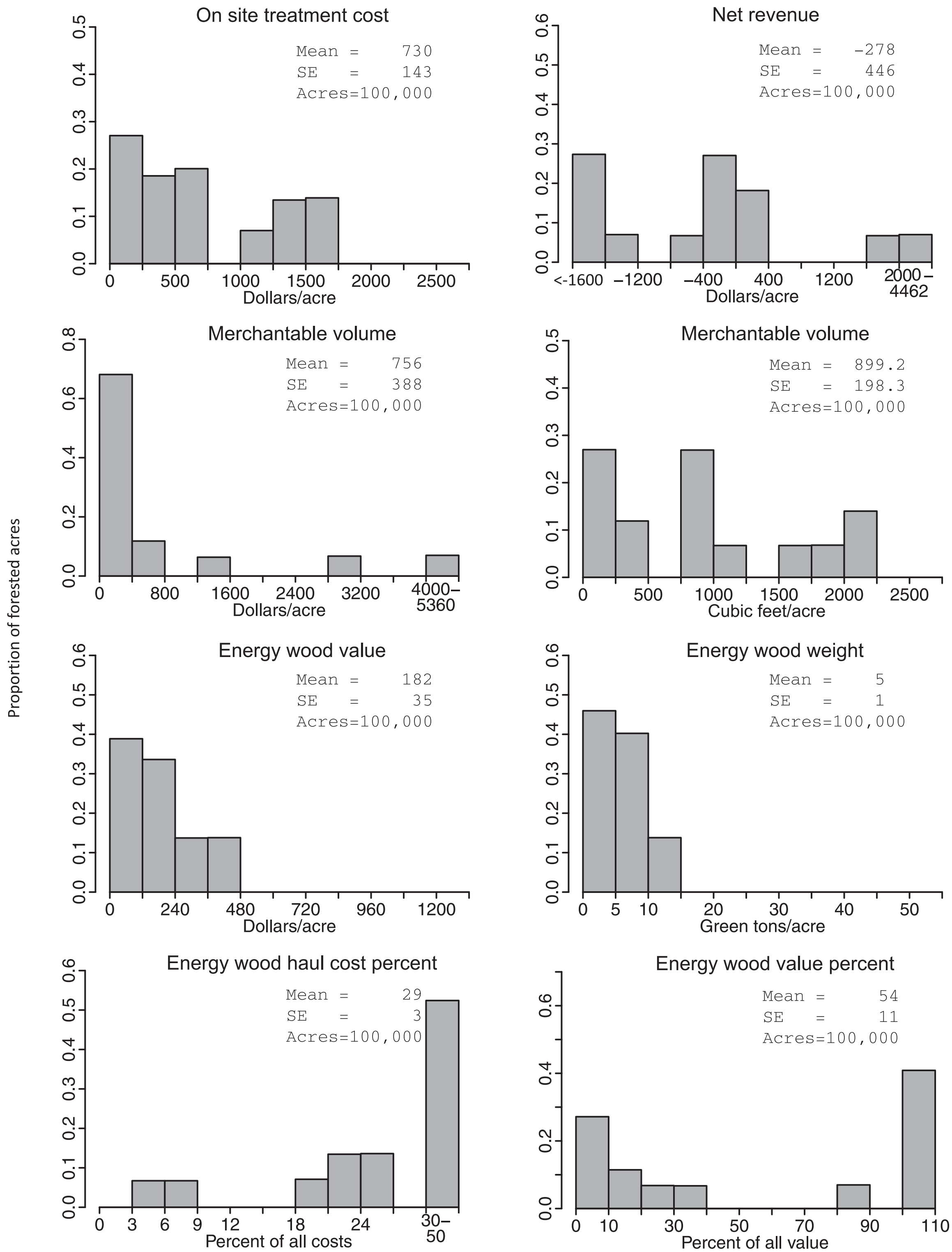
North and Central Rocky Mountains - Pine and Western Larch



North and Central Rocky Mountains - Other Species



Utah - Other Species



Appendix D: Common and Scientific Names of Species

These tables provide the Latin and authorities for the species that were referred to in the synthesis. We also provide the plant symbols. The tables are organized by tree species; understory plant species beginning with grasses, sedges, forbs, and shrubs; diseases; and wildlife species and insects.

Tree Species

Table 1. List of tree species and associated scientific name and symbol.

Common name	Scientific name	Plants symbol
Bigleaf maple	*Acer macrophyllum* Pursh	ACMA3
Blue oak	*Quercus douglasii* Hook. & Arn.	QUDO
Blue spruce	*Picea pungens* Engelm.	PIPU
Bristlecone pine	*Pinus aristata* Engelm.	PIAR
California black oak	*Quercus kelloggii* Newberry	QUKE
California foothill pine/ gray pine	*Pinus sabiniana* Douglas ex Douglas	PISA2
California laurel	*Umbellularia californica* (Hook. & Arn.) Nutt.	UMCA
California white oak	*Quercus lobata* Née	QULO
Canyon Live oak	*Quercus chrysolepis* Liebm.	QUCH2
Chinquapin	*Chrysolepis* Hjelmquist	CHRYS15
Cottonwood	*Populus* L.	POPUL
Coulter pine	*Pinus coulteri* D. Don	PICO3
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	PSME
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.	PIEN
Foxtail pine	*Pinus balfouriana* Balf.	PIBA
Gambel oak	*Quercus gambelii* Nutt.	QUGA
Giant chinquapin	*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmqvist	CHCH7
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) J. Buchholz	SEGI2
Grand fir	*Abies grandis* (Douglas ex D. Don) Lindl.	ABGR
Incense-cedar	*Calocedrus decurrens* (Torr.) Florin	CADE27
Jeffrey pine	*Pinus jeffreyi* Balf.	PIJE
Juniper	*Juniperus* L.	JUNIP
Knobcone pine	*Pinus attenuata* Lemmon	PIAT
Limber pine	*Pinus flexilis* James	PIFL2
Live oak	*Quercus agrifolia* Née	QUAG
Loblolly pine	*Pinus taeda* L.	PITA
Lodgepole pine	*Pinus contorta* Douglas ex Loudon	PICO
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carrière	TSME
Noble fir	*Abies procera* Rehder	ABPR
Oregon white oak	*Quercus garryana* Douglas ex Hook.	QUGA4
Pacific madrone	*Arbutus menziesii* Pursh	ARME
Pacific silver fir	*Abies amabilis* (Douglas ex Louden) Douglas ex Forbes	ABAM
Paper birch	*Betula papyrifera* Marsh.	BEPA
Pinyon pine	*Pinus edulis* Engelm.	PIED
Ponderosa pine	*Pinus ponderosa* Lawson and C. Lawson	PIPO
Port Orford cedar	*Chamaecyparis lawsoniana* (A. Murray bis) Parl.	CHLA
Quaking aspen	*Populus tremuloides* Michx.	POTR5
Red alder	*Alnus rubra* Bong.	ALRU2
Red fir	*Abies magnifica* A. Murray bis	ABMA
Redwood	*Sequoia sempervirens* (Lamb. ex D. Don) Endl.	SESE3

(continued)

Table 1. Continued).

Common name	Scientific name	Plants symbol
Rocky Mountain juniper	*Juniperus scopulorum* Sarg.	JUSC2
Shasta red fir	*Abies magnifica* A. Murray bis var. *shastensis* Lemmon	ABSH
Silver fir	*Abies alba* Mill.	ABAL3
Sitka spruce	*Picea sitchensis* (Bong.) Carrière	PISI
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.	ABLA
Sugar pine	*Pinus lambertiana* Douglas	PILA
Tanoak	*Lithocarpus densiflorus* (Hook. & Arn.) Rehder	LIDE3
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	TSHE
Western juniper	*Juniperus occidentalis* Hook.	JUOC
Western larch	*Larix occidentalis* Nutt.	LAOC
Western redcedar	*Thuja plicata* Donn ex D. Don	THPL
Western white pine	*Pinus monticola* Douglas ex D. Don	PIMO3
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.	ABCO
White spruce	*Picea glauca* (Moench) Voss	PIGL
Whitebark pine	*Pinus albicaulis* Engelm.	PIAL

Grasses

Table 2. Common and scientific name with plant symbol for grasses and shrubs.

Common name	Scientific name	Plants symbol
Arizona fescue	*Festuca arizonica* Vasey	FEAR2
Beargrass	*Xerophyllum tenax* (Pursh) Nutt.	XETE
Big bluestem	*Andropogon gerardii* Vitman	ANGE
bluebunch wheat grass	*Pseudoroegneria spicata* (Pursh) Á. Löve	PSSP6
California fescue	*Festuca californica* Vasey	FECA
Cheatgrass	*Bromus tectorum* L.	BRTE
Elk sedge	*Carex garberi* Fernald	CAGA3
Geyer's sedge	*Carex geyeri* Boott	CAGE2
Idaho fescue	*Festuca idahoensis* Elmer	FEID
Pinegrass	*Calamagrostis rubescens* Buckley	CARU
Rough fescue	*Festuca campestris* Rydb.	FECA4
Sedges	*Carex* L.	CAREX

Shrubs and Forbs

Table 3. Shrub and forb common name, scientific name, and plant symbol.

Common name	Scientific name	Plants symbol
Arnica	*Arnica* L.	ARNIC
Barberry	*Berberis* L.	BERBE
Bearberry	*Arctostaphylos alpina* (L.) Spreng.	ARAL2
Bitterbrush	*Purshia* DC. Ex Poir.	PURSH
Black sagebrush	*Artemisia nova* A. Nelson	ARNO4
Buckbrush	*Ceanothus cuneatus* (Hook.) Nutt.	CECU
Bush chinquapin	*Chrysolepis sempervirens* (Kellogg) Hjelmqvist	CHSE11
California buckthorn	Frangula californica (Eschsch.) A. Gray	FRCA12
Canada thistle	*Cirsium arvense* (L.) Scop.	CIAR4
Cascade barberry	*Mahonia nervosa* (Pursh) Nutt.	MANE2
Ceanothus	*Ceanothus* L.	CEANO
Common juniper	*Juniperus communis* L.	JUCO6
Creeping barberry	*Mahonia repens* (Lindl.) G. Don	MARE11
Currant/ gooseberry	*Ribes* L.	RIBES
Dwarf silktassel	*Garrya buxifolia* A. Gray	GABU2
Greenleaf manzanita	*Arctostaphylos patula* Greene	ARPA6
Heartleaf arnica	*Arnica cordifolia* Hook.	ARCO9
Kinnikinnick	*Arctostaphylos uva-ursi* (L.) Spreng.	RUV
Leafy spurge	*Euphorbia esula* L.	EUES
Lupine	*Lupinus* L.	LUPIN
Mallow ninebark	*Physocarpus malvaceus* (Greene) Kuntze	PHMA5
Manzanita	*Arctostaphylos* Adans.	ARCTO3
Mountain big sagebrush	*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.)	ARTRV
Mountain mahogany	*Cercocarpus* Kunth	CERCO
Oceanspray	*Holodiscus discolor* (Pursh) Maxim.	HODI
Oregon grape	*Mahonia aquifolium* (Pursh) Nutt.	MAAQ2
Pacific poison oak	*Toxicodendron diversilobum* (Torr. & A. Gray) Greene	TODI
Pinemat manzanita	*Arctostaphylos nevadensis* A. Gray	ARNE
Rhododendron	*Rhododendron macrophyllum* D. Don ex G. Don	RHMA3
Rocky mountain maple	*Acer glabrum* Torr.	ACGL
Rose	*Rosa* L.	ROSA5
Salal	*Gaultheria shallon* Pursh	GASH
Scouler's willow	*Salix scouleriana* Barratt ex Hook.	SASC
Serviceberry	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.	AMAL2
Sitka alder	*Alnus viridis* (Chaix) DC. ssp. sinuata (Regel) Á. Löve & D. Löve	ALVIS
Snowberry	*Symphoricarpos albus* (L.) S.F. Blake	SYAL
Snowbrush ceanothus	*Ceanothus velutinus* Douglas ex Hook.	CEVE
Spirea	*Spiraea* L.	SPIRA
Spiraea	*Spiraea betulifolia* var. *lucida* (Doublas ex Greene) C.L. Hitchc.	SPBEL
Sticky currant	*Ribes viscosissimum* Pursh	RIVI3
Thimbleberry	*Rubus parviflorus* Nutt.	RUPA
Thinleaf huckleberry	*Vaccinium membranaceum* Douglas ex Torr.	VAME
Twinflower	*Linnaea borealis* L.	LIBO3
Vine maple	*Acer circinatum* Pursh	ACCI
Western azalea	*Rhododendron occidentale* (Torr. & A. Gray) A. Gray	RHOC
Whiteleaf manzanita	*Arctostaphylos manzanita* Parry	ARMA
Wild ginger	*Asarum* L.	ASARU
Queen cup beadlily	*Clintonia uniflora* (Menzies ex Schult. & Schult. f.) Kunth	CLUN2

Diseases

Table 4. A variety of diseases occur in the dry mixed conifer forests.

Common name	Scientific name
	Stem decay
Blue stain	*Ophiostoma* spp./*Ceratocystis* spp.
Indian paint fungus	Echinodontium tinctorium
Pini rot	Porodaedalea (Phellinus) pini
Pouch fungus	Polyporus volvatus
Red belt fungus	Fomitopsis pinicola
Schwinitzii butt rot	Phaeolus schweinitzii
	Cankers
Atropellis canker	*Atropellis piniphila*
Fir canker	*Cytospora kunzei*
Spruce canker	*Cytospora kunzei*
	Root disease
Annosus	Heterobasidion annosum/ *Heterobasidion parvporum*
Armillaria	*Armillaria* spp.
Blackstain	*Leptographium wageneri* var. *wageneri*
Laminated root rot	*Phellinus weirii*
Tomentosus root disease	*Inonotus tomentosus*
	Rusts
White pine bliser rust	*Cronartium ribicola*
Camandra & Stalactiform	*Cronartium comandrae/ Cronartium coleosporioides*
	Branch and terminal
Mistletoe	*Aceuthobium* spp.
Needle cast	*Lophodermium* spp.
Swiss needle cast	*Phaeocryptopus gaeumannii*
	Foliage diseases
Brown felt blight	*Neopeckia coulteri/ Herpotrichia juniperi*
Larch needle blight	*Hypodermella laricis*
Spruce broom rust	*Melampsorella caryophyllacearum*
Sudden oak death	*Phytophthora ramorum*
Western gall rust	*Peridermium* (*Endocronarium*) *harkessii*

Wildlife and Insects

Table 5. List of the various species we referred to in the synthesis with their common and scientific name.

Common name	Scientific name
Mammal carnivores	
American marten	*Martes americana*
Fisher	*Martes pennanti*
Canada lynx	*Lynx* canadensis
Mammal herbivores	
Deer mice	*Peromyscus*
Porcupine	*Erethizon dorsatum*
Red squirrel	*Tamiasciurus hudsonicus*
Snowshoe hare	*Lepus americanus*
Birds	
Northern spotted owl	*Strix occidentalis caurina*
Pileated woodpecker	*Dryocopus pileatus*
Reptiles	
Gopher snakes	*Pituophis catenifer*
Western skink	*Plestiodon skiltonianus*
Insects	
Cedarbark beetles	*Phloeosinus* spp.
Defoliating weevil	*Pissodes* spp.
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Fir engraver	*Scolytus ventralis*
Larch Casebearer	*Coleophora larcella*
Larch sawfly	*Pristophora erichsonii*
Lodgepole terminal weevil	*Pissodes terminalis*
Metallic wood borers	*Buprestidae* family
Mountain pine beetle	*Dendroctonus ponderosae*
Pine engraver beetle	*Ips* spp.
Roundhead borers	*Cerambydicae* family
Spruce beetle	*Dendroctonus rufipennis*
Western pine beetle	*Dendroctonus brevicomis*
Western spruce budworm	*Choristoneura occidentalis*

Appendix E. English to Metric Unit Conversions

We present values and numbers in English units because many FFE-FVS and some of the Fire Behavior models use English units. However, because this synthesis is not limited to the United States, we include the following English to metric conversion table.

Table 1. Weights and measures conversion used in the United States and United Kingdom and their metric equivalent.

Weights and measures	Metric equivalent
Acre	4047 m^2 or 0.404686 hectares
Foot	30.48 cm, 0.305 m
Inch	2.54 cm
Mile	1.609 km
Basal area ft^2 per acre	0.205921151 m^2 per hectare
2.47105 acres	1 hectare

Rocky Mountain Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

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